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(71)(72) Applicant and Inventor: CARMEIN, David, E., E. [US/US]; 9200 Russel Avenue South, Bloomington, MN 55431 (US).

(74) Agent: BARTZ, Richard, O.; 1300 Foshay Tower, Minneapolis, MN 55402 (US).

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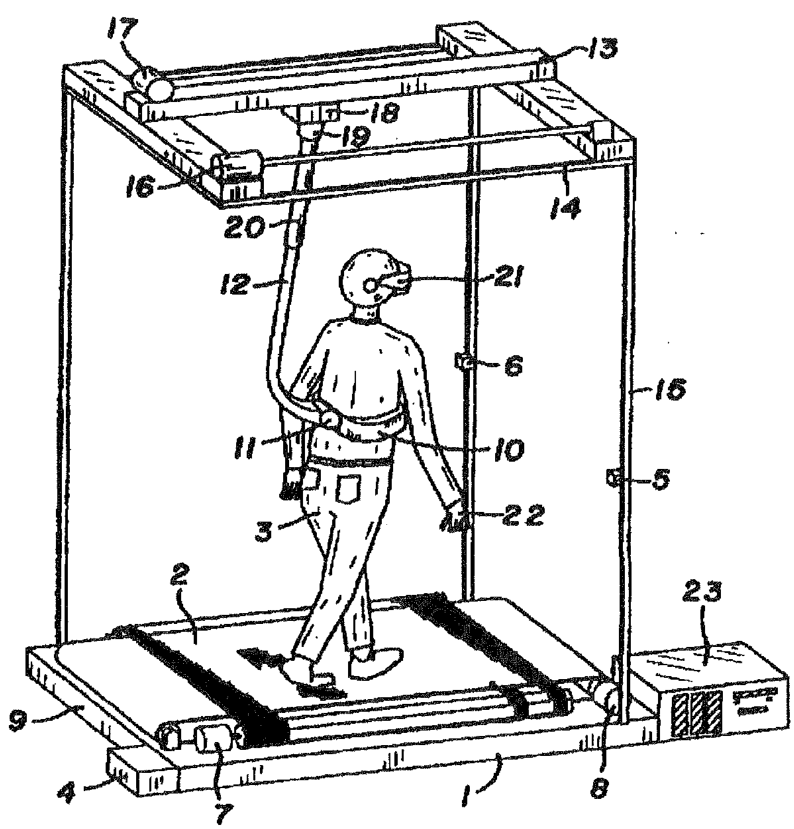
(54) Title: OMNI-DIRECTIONAL TREADMILL

(57) Abstract

A treadmill (1) having a track assembly that allows a user (3) to walk or run in any arbitrary direction. A movable user support has a plurality of rotatable members that rotate about axes normal to the direction of movement of the user support (2). Separate power driven mechanisms (7, 8) concurrently move the user support (2) and rotate the members to omi-directional user movement. A control (4) for the power driven mechanisms (7, 8) is responsive to the directional orientation of the user on the user support (2) to cause the user support (2) to operate in the direction of the orientation of the user (3).



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OMNI-DIRECTIONAL TREADMILL

FIELD OF THE INVENTION

The invention is in the field of human rehabilitation, simulation, training, exercise equipment, and generally methods that permit the user of the equipment to walk, run or crawl in any arbitrary direction and employing haptic sensing to increase a user's level of immersion in the simulated environment.

BACKGROUND OF THE INVENTION

Virtual Reality (VR) typically employs computer-generated stimulation of the human sensorium to simulate naturally occurring inputs such as sight and sound. Additional senses which may be stimulated include orientation, balance, and touch and force (haptic) feedback. A complete and immersive VR experience might simultaneously stimulate a user with sight, sound, touch, and movement.

A major limitation in state-of-the-art VR is the inability to permit simple walking and running. Navigation is typically experienced as a disembodied center of consciousness which is directed by pointing, other gesture or by manipulation of a joystick, trackball, mouse, or similar device. The actual physical sensation of walking is limited to one of two forms: a) The user is restricted to a confined and immobile surface where tracking and signal generation are well-controlled, and b) the user is confined to a device such as a linear treadmill or wheelchair which transduces the user's linear motion from real space to virtual space. The conventional linear treadmill has a movable track which may optionally be upwardly inclined. The track is only movable in one direction which restricts motion of the user to the direction of movement of the track. A monitor, such as a motivational electric display, associated with the

track, records the time, speed, and distance accomplished by the user.

Use of a linear treadmill in a virtual environment consists of, one continuous moving track, and in conjunction with an external monitor or head mounted display permits a user to walk in a straight line. The user cannot step in arbitrary directions as s/he would be able to in real life. This limitation in navigation detracts from the immersive nature of the experience, and requires that the experience takes on more of a vehicular nature rather than that of a freely walking and navigating body.

SUMMARY OF THE INVENTION

The invention describes herein is most similar to a linear treadmill in that the user is able to walk or run in an upright manner. The user may also employ proprioceptive sensing to imbue a sense of touch to the simulated environment. Alternatively, the user may assume any of a manner of postures with respect to the planar active surface. Other postures include kneeling, crawling on hands and knees, belly crawling, and sitting and lying prone.

The invention is an omni-directional treadmill apparatus that allows a user, such as a person, to move, walk, run or crawl in any arbitrary direction. The apparatus has a frame for supporting the apparatus on a fixed surface. A track assembly mounted on the frame provides a user support that moves in a direction determined by directional orientation of the user on the track assembly. The track assembly has a user support movable in first direction by a first drive motor. The user support includes user support members rotatable about axes generally normal to the direction of movement of the support. A second drive, such as a power driven endless belt, engages the user support members to rotate the user support members whereby the combined movement of the user support members and user supports results in

omni-directional user movement. Controls responsive to the directional orientation of the user on the user support drives which in turn controls the directional user movement to conform with the orientation of the user on the user support.

DESCRIPTION OF THE DRAWINGS

Figure 1 is a perspective view of the omni-directional treadmill of the invention;

Figure 2 is a block diagram of the motor control of the treadmill;

Figure 3 is a perspective view of a first modification of the treadmill of the invention;

Figure 3a is an enlarged sectional view taken along line 3a-3a of Figure 3;

Figure 4 is a perspective view of a second modification of the treadmill of the invention;

Figure 5a is a perspective view of a third modification of the treadmill of the invention;

Figure 5b is a perspective view of a section of the track assembly employed in the treadmills of Figures 1 to 5;

Figure 6 is a perspective view of a section of the track assembly employed in the treadmills of Figures 1 to 5;

Figure 7 is a perspective view of the track assembly employed in the treadmills of Figures 1 to 5;

Figure 8 is a diagrammatic perspective view similar to Figure 6 showing the movement of the rotatable sleeves and sleeve drive belt;

Figure 9 is a perspective view of first modification of the track assembly useable with the treadmills of Figures 1 to 5;

Figure 10 is an exploded perspective view of a section of second modification of the track assembly useable with the treadmills of Figures 1 to 5;

Figure 11 is a perspective view of a modification of the omni-directional wheel and idler

rollers;

Figure 12 is a perspective view of a third modification of the track assembly useable with the treadmills of Figure 1 to 5;

Figure 13 is a perspective view partly sectioned of a spheroid treadmill segment;

Figure 14 is a sectional view of the segment of Figure 13 incorporated in a track assembly;

Figure 15 is a perspective view of another modification of the active surface of the track assembly;

Figure 16 is a perspective view of Figure 4 combined with a hexapod motion platform;

Figure 17 is a perspective view of an active surface haptic display;

Figure 18a and 18b are diagrammatic views showing the user at one site to control a remote at a distal site;

Figure 19 is a perspective view is a further modification of the track assembly useable with the treadmills of Figures 1 to 5;

Figure 20 is a section view taken only line 20-20 of Figure 19;

Figure 21 is a enlarged cross sectional view of a portion of the bell assembly;

Figure 22 is a perspective view of a section of yet another modification of the track assembly of the omni-directional treadmill of the invention;

Figure 23 is an enlarged perspective view of the longitudinal roller and transverse roller illustrating the X and Y vector due to rotation of the rollers; and

Figure 24 is a transverse cross section of longitudinal roller located in engagement with the transverse roller.

DETAILED DESCRIPTION

The invention avoids the limitations of a traditional treadmill by permitting a user to walk in any arbitrary direction. Figure 1 depicts an Omni-Directional Treadmill (ODT) 1 with an active surface 2 which cleverly employs a unique mechanism by which a user 3 positioned at any location on the active surface may be transported to any other point an that surface. More typically, a user who is headed off the active surface is moved back toward the center of the surface analogous to the way a linear treadmill prevents a user from running off the front or being flung off the back.

Integral to the ODT is a closed-loop motor control mechanism 4 and a user position-sensing device 5, 6 which pinpoints the position of the user with respect to the fixed axes of the treadmill's active surface. These two work in concert with X axis control motor 7 and Y axis control motor 8 to ensure proper positioning of the user on the active surface, which is fixedly attached at selected points to a rigid base 9. In the embodiment of Figure 1, the position sensors are ultrasonic transducers of a design well known to those skilled in the art of ultrasonic position sensing.

To address the problem of balance, the ODT optionally includes a means for steadying the user. A structure as simple as a circular railing may suffice. More preferable from the standpoint of transparency is the use of a balance cuff 10 which attaches near the user's center of balance. A hinge 11 at the small of the user's back connects the cuff 10 to a support strut 12 which serves to link the user with the X-Y tracking mechanism 13 of the support frame 14. Under normal circumstances, the cuff 10 permits active X-Y tracking of the user because the support strut 12 actively maintains a vertical position. In this fashion, the user barely knows the cuff 10 is there. When the user becomes unstable, however, the cuff 10 serves to assist

in regaining balance.

In order for the cuff 10 and strut 12 to actively track the user in any orientation, the strut 12 is preferably connected to a support structure 14 directly over the user's head which is supported by at least three vertical support members 15. Two motors 16, 17 actuate the X -Y tracking means respectively to maintain the strut 12 in a vertical position with respect to the user. Motors are controlled by sensing the variance of the strut 12 from the vertical. A pair of X and Y potentiometers 18 sense the angular error of the strut 12 in the XZ plane and YZ plane respectively. An XZ error, for example, indicates that the X motor 16 must drive the mechanism n the direction to reduce the error to zero. Likewise for an error in the YZ plane controlling the Y motor 17. Rotations about Z caused by the user turning are passed through a slip ring assembly 19. The slip-ring assembly 19 prevents a winding or twisting of the strut 12, and also permits passage of electrical power and signals through rotary electrical contacts so that a connection may be maintained with the equipment worn by the user. Slip-ring assemblies are readily known to those familiar with rotary electrical contacts. In a similar fashion, the vertical motion of the user is permitted by an extension mechanism 20. The extension mechanism 20 allows only linear motion, and permits passage of electrical signals to and from the user.

The preferred embodiment of the device is a combined ODT/VR system as revealed in Figure 1. It allows close coupling of the user's physical direction and velocity with that of the virtual world in which the user is navigating. Such a system might typically include a head mounted display (HMD) 21 with speakers and microphone, data glove(s) 22, a body sensing suit (not shown), exoskeletal joint angle sensors, and/or other related apparatus. Said VR system would likely

include a computer 23 for image generation, sound generation, and processing of related data such as head and hand position. Though not explicitly shown, peripherals worn by the user are hard-wire connected to the computer system through wires running up the strut 12, through the X - Y tracking support 13, and down the support frame vertical member 15. Wireless connections are also possible using electromagnetic or infrared means.

The ODT works in synchrony with the VR system by sending velocity and direction signals to the image generation computer. The computer uses the velocity vector thus provided to update what is shown to the user so that the user sees a visual image which takes into account this vector. For example, if the user's velocity is 1/2 meter/sec in the X direction as indicated by the X direction motion of the treadmill, the user will observe objects within the virtual world passing by at 1/2 meter/sec in the minus x direction.

Variations of the combined ODT/VR system include the ability to tip the platform to simulate uphill travel, and networked VR experiences in which one user shares a virtual world with others.

Additional variations to the ODT/VR system include integration of sensing and stimulation systems. Examples of additional sensing might optionally include full or partial human surface mapping, video capture, or their combination, which can then be manipulated and transported as the user's virtual image. A companion traveller in virtual space would then see a real-time facsimile of the user.

A further enhancement of immersion and realism within the virtual environment may be achieved by addition of force feedback to the user's whole body rather than just a specific appendage. A main object of a downhill direction as well.

A user on a treadmill without force feedback

is not doing significant work. Through the basic definition of work equals force times distance, we see that a user without an externally applied force is not able to exert work. The only exertion by the user is to lift and place legs and to generally maintain balance through placement of arms and body motion.

By applying external force, typically at or near the user's center of mass, the system permits the user to do work. Force applied to the user is matched by an average equal and opposite force of the feet upon the treadmill. If the treadmill surface is moving, the user is made to do work per the basic equation: work is equal to the sum of the applied forces of each foot times the distance traveled as the force is applied. The rate at which that work is done is determined by the velocity of the action surface and is equal to the power exerted by the user.

With reference to Figure 1, the user 3 is walking on the ODT's active surface 2 and is coupled to a force feedback system through a centrally located cuff 10. The cuff is attached to a strut 12 which can be made to apply appropriate amounts of force at selected height in a direction generally opposite to the linear direction of travel. A generally equal and opposite force is generated by the user on the surface of the treadmill, and that force occurs along the same linear direction as the direction of the treadmill's surface velocity. It is the force of exertion along the direction of motion at velocity V which demands exertion from the user.

Externally applied force as described above, may be straightforwardly combined with a tilted active surface to enhance the illusion of traveling uphill. In addition, the angle of the applied force may be varied to simulate various loading conditions.

Figure 2 is a block diagram for the control of a single motor. This motor and its affiliated control

loop may actuate either the X or Y control for either the active surface or the support cuff tracker.

With reference to Figure 2, for a single axis of the active surface,the Control Signal is set for zero at the center of the surface. If the position Signal is off-center, the Summing Junction generates an Error signal which is proportional to the error. A PID (proportional-integral-differential) Controller, which is well known and well characterized to those familiar with the art of motion control, is tuned to interpret the error signal over time, outputting a signal which controls motor velocity along one axis. Motor velocity and its associated direction are interpreted by the VR system as a velocity and a direction, and the image presented to the user is updated accordingly. Motor velocity also causes the active surface to be driven in a direction which reduces the Error. The Plant represents the system components, including the user, which are responsible for generation a position signal. In this case, the plant includes the active surface as it is driven back toward center, the user, who is being driven back toward center by the motion of the surface, and the position transducers, which sense the absolute position of the user with respect to the zero reference position, and generate the Position Signal which may be resolved by the Summing Junction.

Control of a support cuff tracking motor occurs in a similar fashion. With reference to Figure 2, the Control Signal is set for zero when the support strut is vertical with respect to its active axis. If the Position Signal shows an angle other than zero, an Error signal is generated which is proportional to the angular error. The PID controller outputs a signal for the motor controlling the axis of interest, which turns at the specified velocity. The Motor Velocity drives the mechanism of the Plant in the direction to reduce the error to zero, and the next cycle is begun again.

In the device of Figure 1, the position signal might be generated by a rotary potentiometer 17 which is affiliated with the axis of interest.

An alternative embodiment of the cuff support is shown in Figure 3. The user 101 is shown wearing a harness 102 rather than a cuff 10 of the type shown in Figure 1. In this case the harness is flexibly connected through a hinge 103 to a rigid horizontal member 104. Said member is hingedly connected to a vertical member 105, which is hingedly connected to a rotating fixture ring 106. Ring 106 is rotatably held within the base 107. In the section view we see that the fixture ring is fastened to a gear ring 108 which rests on a dual bearing race 109 supported by a bearing ring 110. The gearing is restrained from transverse movement by the bearing race grooves, and is constrained in the upward direction by roller contacts 111. Ring 106 is driven about its center by geared contact with a spur gear 112, which is driven by the drive motor 113 through a gear reduction means 114.

Shear sensors within the cuff 115 of at the hinge 103 generate a signal which is analogous to the Error signal of Figure 2. The motor 113 drives the ring in a direction to reduce the shear sensor output toward zero. In this manner the cuff and support struts track the user's position, providing support and balancing assist to the user along with a hard-wired connection to the HMD and sound system. In all other respects, the active surface 116 of the ODT behaves the same as that in Figure 1. For clarity, the position sensors, motor drivers, and computers are omitted form the Figure 3.

Even better support may be provided to the user by making the hinge support 117 of the horizontal member 104 and the hinge support 118 of the vertical member active members, i.e., they can be actively damped. Active damping would sense the rate at which the user is moving, and would increase damping in

proportion to the velocity of movement. In this way, if the user should fall or loose balance, the rapid change in velocity would cause much increased damping at the hinges, and would provide the support needed to regain balance.

A non-motorized version of the embodiment of Figure 3 would employ a hand grip for steadying balance, as shown in Figure 4, rather than the actively tracking cuff of Figures 1 and 3. The hand grip 201 attaches through a horizontal member 202 through a hinge 203 to a vertical member 204. The vertical member 204 is attached through a hinge 205 to a ring 206 of the type depicted in Figure 3 which is rotatably attached to the base 207. Because the ring rotates around the user (not shown) under power of the user, there is no motor. The user would always have at least one hand on the hand grip, and would apply forward and backward force, and torque to the handle to properly position it as they moved about the active surface 208. This embodiment of the invention, though reduced in features, would be lower cost to manufacture and would require less ceiling height. The unit could be comfortably installed in the home or office without special height or power requirements. For clarity, the user, position sensors and computers are omitted from the Figure 4.

Haptic interaction may be accomplished through use of passive or dynamic "interactive solids" also referred to generally as "haptic displays." Figures 5a and 5b show how such haptic displays might interact with the user. Figure 5a depicts a user in real space. Here we see the user 301 standing on the ODT 302, supported as before by a cuff and strut assembly 303. The user is reaching out and touching a flat, horizontal surface 304 upon which he is about to sit. The surface 304 is controllably placed by a motorized strut assembly consisting of a horizontal member 305, a vertical member 306, and hinge control motors 307, 308, 309. This

positioning assembly is fixedly mounted on a secondary mounting ring 310 of the type first shown in Figure 3a. The ring 310 is powered and positioned by a motor 311 in a fashion similar to that of the motor depicted in Figure 3. The surface 304 may be controllably placed by suitable rotation of the ring 310, and turning of the hinge motors 307-309.

Figure 5b depicts visual reality as seen by the user of Figure 5a. In the virtual space of Figure 5b, the user 401 sees and physically interacts with the surface of Figure 5a where it appears as a chair 402. This is an example of a dynamic interactive solid because it passively interact with the user to solidify the synthetic visual reality. Once the solid finds its place the user's real and virtual space, it remains fixed. A second chair 403 which is within the user's virtual work is also available to sit upon. If the user were to choose the second, lower chair, he would simply turn and walk to that chair. The ring 310 of Figure 5a will swing the interactive solid 304 to correspond with the anticipated surface of the second chair, and the user may touch it and sit upon it.

A dynamic interactive solid differs from the passive one described above in that it actively responds to a user's input, input from a user sharing the same virtual space, or an operator completely outside the virtual environment. A dynamic interactive solid responding to a user might be, as in the previous example, a horizontal surface which represents the top of a floating surfboard. As the user pushes down, the surface, under the closed loop control of an external computer, provides the same bobbing and floating response that a real surfboard would provide. A more complete dynamic interactive solid might be a mechanical hand which is felt by the user but controlled by another within the virtual environment. The user might squeeze and shade the hand, and it will squeeze and shake back

in response because the parallel user is squeezing and shaking an identical hand in his or her own virtual environment.

Passive and dynamic interactive solids are not restricted to the circular-ring embodiments of Figure 3 to 5. They may just as easily be implemented within the embodiment of Figure 1 and its related variations. An example of such a hybrid system would include above-mounted cuff support, passive and dynamic interactive solids.

The invention is not restricted to the use of a balance cuff. ODT's with larger surface areas and gentle centering action may not need a cuff to support and balance a user. A large active surface area allows restorative forces to be gentle enough to avoid upsetting the user's balance.

Interactive solids are referred to the literature as "haptic displays" or "roboxels". Related work has evolved interactive surfaces such as circular plates and shafts with torque feedback (Good, U.S. Pat. No. 5,185,561). It is in the spirit of the invention to optionally include both passive and dynamic interactive, reality-enhancing means as integral to the function of the ODT.

USES

By itself, the ODT is useful as:

1. An exercise device
2. A motion analysis device for movement in arbitrary directions
3. A Training device for lateral moves in arbitrary directions

Combined with the VR system, the ODT is useful for:

1. Virtual space navigation
2. Training
3. Telepresence
4. Entertainment

5. Exercise
6. Recreation
7. Motion analysis
8. Education
9. Psychological analysis and therapy

DETAILED DESCRIPTION

Basic Mechanism

In order for an active surface to move a resting mass in any direction it must have available two active vector motion components, plus and minus X, and plus and minus Y. A linear treadmill has only +/- X. the ODT has both.

The ODT employs a "vector thrust drive" which mechanically separates the two motion components so that they can be powered and controlled by two separate motors. The vector thrust is the vector sum of the X motion component and the Y motion component.

As shown is Figure 6, the active surface 501 of the ODT, hereinafter referred to as the roller belt, is comprised of a multiplicity of identical roller segments 502. A roller segment consists of a rigid shaft 503 upon which is mounted a freely rotating roller 504 which is kept within its lateral boundaries by spring clips 505 fastened at the ends of the shaft. Ends of the shaft are formed into eye hooks 506, which, in turn, are held around a common hinge axis by a hinge rod 507. Contact points of individual eye hooks are separated by spacers 508 to properly position them and to prevent lateral motion. Each roller frictionally abuts a surface 509, preferably a flexible belt, moving at right angles to the motion of the roller segments, along a line of contact 510 which serves to create selective rotational motion 511 to the roller. The flexible belt is supportively abutted by a rigid support plate 512 which substantially takes the load of the user's weight, and ensures that the active surface remains flat.

X-direction motion 513 of the roller belt 501 is driven by the X-direction motor 7 of Figure 1. Y-direction motion 514 of the flexible belt 509 is driven by the Y-direction motor 8.

Figure 7 shows the complete mechanism for achieving full omni directional motion, and shows that the hinge rod 601 permits the roller belt 602 to flex around rollers 603, 604 at the belt edges. Hex rollers actuate the roller in the +/- X vector direction 605. As shown, rollers are hexagonal in shape to accommodate the hinged nature of the roller belt.

In the embodiment of Figure 7, one hex is powered by a motor 606 while the other is an idler 607, although both rollers could easily be powered. The linearly actuated planar surface 608, which is the top surface of a flat, closed-loop drive belt 609 is placed in intimate contact with the bottom surface of the roller belt 610, and oriented so that its motion is at right angles to the motion of the roller belt. It is supported and directed at its ends by rollers 611, 612. In the preferred embodiment, only one roller is actuated by a motor 613; the other is an idler roller.

Rollers are supported by bearing 614, or by a motor drive shaft 615. The bottom surface of the flat, flexible drive belt 609 is supportively abutted by a rigid support plate 616 which is supported at each of its four corners by support legs 617. The support legs, bearings, and motors are securely fastened to a rigid support surface 618 which serves as ground.

When the roller belt alone is actuated, the top of the roller provide +/- X motion. When the flat belt alone is actuated, it frictionally contacts the bottom surface of the rollers, thus causing them to rotate about their free axis. So, if the belt is moving in the - Y direction 619, the top surface of the rollers is moving in the + Y direction 620, Since the contact lines at the top of each roller are moving in concert,

a mass resting on the active surface 621 defined by the sum of the contact lines is moved in the direction of the combined X and Y motion vectors. The active surface of this Figure 621 may be identified with the active surfaces 2, 116 and 208, shown in Figure 1, 3 and 4.

By actuating the beaded belt and the flat simultaneously, the surface contacts lines of the rollers may by made to impart any combination of X and Y movement. For instance, in Figure 8 we see a roller segment 701 moving at plus 1 foot/second in the minus Y direction 702, and the flat belt 703 is moving at minus 1 ft/second in the minus Y direction 704. The freely-rotating roller converts the belt's -Y motion to a +Y motion at the contact line 705. The combined thrust vector 706 equals the vector sum of the two belt's motions, i.e.,1.414 ft/second at an angle of 45 degrees in the first quadrant.

For better stability, the underside of the flat belt is supported by a smooth, flat rigid surface 707. The interface surface between the flat belt 703 and the support surface 707 is preferably reduced in friction by coating with a slippery substance such as teflon.

A tensioning mechanism is advantageously employed on one of the two rollers in the X direction and one of the rollers in the Y direction, preferably the idler roller, so that any slack or relaxation of the belts may be taken up.

Rollers may be arbitrarily small or arbitrarily large. However, sensible limits are placed on roller size by factors such as ease of assembly. In addition, the size of the hexagonal rollers is determined by the length of the rollers and the hinge segment it defines. Obviously, there is an optimal roller size range for said assembly.

A hexagon shape has been arbitrarily chosen to depict the roller belt actuation means. the roller is

not restricted to this shape, though it is reasonably expected that the roller will have between six and eight sides to optimize the balance between size and manufacturability.

Alternative Active Surface Mechanisms

The vector-slip principle may be employed with discrete components of another form as well. In Figure 9 is seen one corner of the active surface of the ODT 801, which consists of a multiplicity of identical beaded segments 802. A beaded segment consists of a flexible cable 803 upon which is strung a number of a beads 804. The cable is fastened end to end to form a closed loop. Beads are separated by spacers 805. Spacers serve two purposes. For one, they ensure a uniform bead spacing. Two, they impart linear force to the beads 804 as the cable is pulled in either direction. Without the spacers 805 attached to the cable 803, the cable 803 would tend to pull through the beads 804 rather then force them in the desired direction.

Rollers 806 (only one shown) support and direct the return loops 807 at the segment ends. Adjacent segments are fastened to each other by the spacer mechanisms 805. The combination of adjacent bead segments and their associated spacers forms a uniform surface to beads, which is directly analogous to the uniform surface of the roller belt. As with the roller belt system, said beads are actuated in the +/-X direction by one set of rollers, and are actuated in the +/-Y direction by contact with a flat belt 808.

Rather than stringing components on wire and fastening them together, it is also possible to fabricate a single, repeating construction unit which accomplishes the same function as the wire and bead assembly. Figure 10 depicts such a repeating unit. A bead 901 or roller is rotatable mounted on a shaft 902 which has a male 903 a female 904 end as well as a

connecting strut 905. Beads are connected into closed-loop strings by fastening the male portion of the assembly into the female. Connections between strings of beads are made by mounting the hole of the strut 906 over the male portion of the adjacent string. It is understood that said repeating, componentized structures are also suitable for construction of a roller-type unit which duplicate the function of the above-described roller belt.

Following assembly of all the bead segments which comprise a roller belt, the assembly will look much as that depicted in Figure 9, except the spacers 805 will be an integral part of each unit assembly 905 as separate connecting struts.

Figure 11 reveals yet another omni-directional surface actuation means which uses a wheel 1001 with idler rollers 1002 positioned around its circumference. An idler roller unit 1003 is inserted into the appropriate receptor notch in the wheel 1001. Each idler axis 1004 is oriented perpendicular to the powered axis 1005 of the wheel. The vector-slip wheel 1001 has the unique property of being able to transmit force only through a line perpendicular to the powered axis 1006, the x axis. Any motion which the wheel 1001 sees in the Y axis passes over the idlers 1007.

Figure 12 shows that by combining the above-described vector-slip wheel in an array of X oriented wheels 1101 and Y oriented wheels 1102, a combined direction vector may by achieved by selective actuation of the x and Y arrays. The wheels 1102 are actuated in the y direction by one set of belts 1103, and in the X direction by another set of belts 1104 which contact the bottoms of the wheels. These belts are held and directed by a base 1105 with guide grooves and mounts for the wheel arrays. Wheel 1106 is a typical X-direction wheel of the construction of Figure 11. It is held onto the base by snap fitting its axis 1107 into

snap grooves of a pair of mounting posts 1107, where only one post is shown. Every wheel is held onto the base in the same manner.

Because the X wheels 1001 are a larger diameter than the Y wheels 1102, the contacting belts do not come into contact with one another. As with the beaded belt invention, actuation of the X wheel array actuates motion in the +/- X direction which passes easily over the idlers of the Y vector-slip wheels with no hinderance. Pure Y motion is likewise unhindered by the X array. As long as a resting mass contacts a reasonable number of X and Y rollers, combining X and Y wheel arrays permits an active surface which is able to linearly actuate the resting mass in any direction through combination of the X and Y vectors.

Drive belts 1103, 1104 are continuous belts which are driven by rollers (not shown). The rollers are powered and controlled by motors in a fashion similar to the roller/motor combination of Figures 1 to 4 and Figure 7.

Ergotech, Inc. makes an assortment of large rollers which employ shaped idler pulleys on their exterior which fall into the same class as the vector-slip wheel. Their use is as passive moving devices for boxes and other flat-bottomed articles.

Martin-Marietta has employed a vector-slip drive on a lunar rover 7. Their idler rollers are oriented at 45 degrees to the main wheel drive axis. Thrust is therefore always at 45 degrees to the main wheel drive axis. By proper combination of the four thrust vectors available from the four wheels, the rover is able to navigate in any arbitrary planar direction.

One advantage of the method of discrete construction units is that their hinged nature allows better control of the active surface topography. By making the material of the flat belt flexible and deformable, and by supporting the underside of the flat

belt with a multiplicity of individually controllable idler rollers, each support point may be selectively raised or lowered. By selectively raising or lowered idler support points on the flexible underside of the flat belt, and by jointedly connecting discrete construction units to form the beaded active surface, the active surface may be deformed with controllable bumps and depressions. The bumps and depressions might be advantageously shown as matching bumps and depressions in the virtual environment, thus enhancing the reality of the immersive experience.

In a comparable fashion, the vector-slip wheels of Figure 11 and 12 may be individually raised and lowered to simulate a surface of varying texture. Since the vector-slip wheels are discrete units rather than tied in to a belt, they may be raised and lowered substantially more than their roller or bead counterparts. In this embodiment, because vector-slip wheels are potentially decoupled from their support surface, it is no longer possible to drive them using belts as shown in Figure 12. Each wheel must be individually actuated using separate drive means. While more complex, this arrangement is the only one of the aforementioned systems which permits simulation of complex tasks such as climbing stairs while retaining the advantage of an ODT.

Figure 13 reveals yet another embodiment of an ODT which employs a moveable, continuous, active surface 1201 that wraps around a flattened spheroid 1202. The active surface 1201 is held onto the surface of the spheroid by its own elasticity, and the contact zone between the rigid spheroid and the moving surface 1203 is relatively frictionless. By sliding the active surface around the spheroid by its own elasticity, and the contact zone between the rigid spheroid and the moving surface 1203 is relatively frictionless. By sliding the active surface 1201 around the spheroid, the

flat portion at the top of the spheroid 1204 will serve the same function as the active surface of earlier figures.

Figure 14 is a cross section of the fully implemented spheroid construction of Figure 13. The ODT 1301 shows an active surface 1302 which stretchably surrounds the rigid spheroid 1303, separated by a relatively frictionless layer 1304. The housing 1305 retains the active surface and spheroid by mounting passive casters which substantially retain the top 1306 and bottom 1307 contours of the fundamentally spheroid shape, and by presenting a slight overhang to retain motion of the assembly in the upward direction.

The active surface is controllably actuated by frictional contact with a steerable roller 1308. The roller 1308 is steerable about two axes. Axis one 1309 is powered by a motor 1310 about the roller itself, thus driving the bottom side of the active surface by frictional contact. Axis two 1311 driven by motor 1312 provides steerability of the roller so that the roller can direct its thrust vector in a full circle. A thrust vector provided by the roller causes the active surface to slide around the spheroid. As depicted, with the roller providing thrust on the lower surface substantially in the +X 1313 direction, the upper surface responds in the -X 1314 direction.

Figure 15 details one potential embodiment of a small area of the active surface 1401. A pattern of rigid plates is arranged to form an array of hexagons 1402 and pentagons 1403, much like the surface of a soccer ball. Corners of the plates are held together elastically 1404, so that the surface may expand and contract appropriately as it traverses the spheroid. the underside of each plate is suitably supported by an arrangement of casters 1405 which are pressed into the rigid material of the plate. The casters 1405 permit contact between the plate and the spheroid to be low in

friction, as required for proper function.

An improvement on the embodiment of the powered roller 1308 of Figure 14 would be to split the roller function into two rollers actuated by differential gear unit. It may then still be powered by two motors as revealed above, however it would gain the advantage of minimizing rotational friction during steering, much the same way an automobile differential permits the drive wheels of a turning car to rotate at their own speed.

In is understood that the surface construction of Figure 15 is exemplary, and represents only one of a class of surface constructions which fulfills the function of a flexible, low-friction active surface interacting with a contained, flattened, spheroid.

Advanced System Configurations

Although the basic system configuration includes a support cuff for assistance of balance and optionally for tracking user orientation, it also has the potential to completely like and support the user. A strengthened and fully actuated support strut connected to a fully supporting cuff and harness enables a user to be lifted up from the active surface and move within the confines of the mechanically limited motion envelope. A system of this type would allow a user to transition between active surface locomotion and free-body flight.

In a similar fashion, the entire active surface and related mechanism may be mounted upon a motion platform which permits various combinations of linear and angular motions of the surface. A tipped surface is useful for simulating an inclined surface in virtual space, like a user might encounter when walking up a virtual hill. A surface which moves up and down as well as angularly can simulate the deck of a ship, or the cabin aisle of an aircraft.

Figure 16 depicts the combination of the simplified ODT of Figure 4 1501 with a standard 6 degree-of-freedom hexapod motion platform 1502. The base of the ODT 1503 serves as the attachment point for the six linear actuators 1504 which comprise the hexapod. Control of said cylinders provides full 6 DOF motion, and the control of said hexapod structure is well known to those skilled in the art of motion control. Cylinders are attached by ball joints to ground 1505, and by ball joints to the base 1503. Said cylinders may typically be actuated by hydraulics, pneumatics, or by a ball screw mechanism. The power and control means for the hexapod and ODT are omitted from the figure, but are understood to include a power conditioning means, a position sensing means, a control computer, and a control loop of the type described in Figure 2. It is also understood that the ODT which attaches to the hexapod might just as easily be of the construction of Figures 1, 3, 5, 9, 10, 12, 13 or 14.

Combining the ODT with an enclosed simulator such as the spherical motion environment developed by Virtual Space Devices, Inc. would permit not only 3 to 6 DOF to be applied to the active surface of the ODT, but would also allow transitioning between walking, free-body flight, and vehicular simulation.

An ODT need not be the main interface device for an immersive system. It might, for example, be complimentary to a vehicle simulator. A standard simulator for a vehicle such as a jeep, mounted on a hexapod motion platform, could be placed adjacent to an ODT. As the user emerges from the vehicle simulator, the ODT would be positioned at virtual ground so that the user experiences a smooth transition between vehicular transport and ground motion.

The unique, omni-directional qualities of an active surface such as those revealed therein may be employed in yet another way. As a haptic display

device, an active surface is able to convey a sense of friction to a user as they run their hand along a surface. Figure 17 presents an embodiment for a active-surface haptic display 1601. As the user's hand 1602 reaches out to contact a virtual object, the active surface 1603, which is only slightly larger than the major diameter of the user's palm print, is placed by a robotic mechanism 1604 where the user expects that surface to be. As the user moves their hand along the surface in one vector direction 1605, the haptic display mirrors the motion of the hand 1606, while the active surface creates an equal and opposite counter vector 1607 by moving its surface counter to the motion of the hand. The user resultingly feels the friction of the virtual solid's surface as the hand is rubbed across the moving surface. Because of the omni-directional nature of the active surface, the hand may trace an arbitrary path.

In its basic form, the active surface is flat both because the support surface behind the activation means is most easily fabricated as a flat surface, and because the interlinked nature of the active means tends to prevent creation of surface contour. A flat surface will be effective for simulating a flat virtual solid, but it can only approximate a curved solid. A moderate amount of curvature may be achieved, however, by bowing might be accomplished using pressurized air behind a thin and flexible support surface. The amount of bowing may be controlled to correspond to the average curvature at the user's contact point with the virtual solid.

Description of the preferred embodiment as including an HMD, gloves, body suit, etc. does not exclude other applicable system configurations. There are a number of additional display options which may advantageously employ an ODT. For example, Myron Krueger's original display method employs large display screens which surround the user. Spherical display

surfaces have been employed for a number of years by various companies such as IMAX theater, or Evans & Sutherland. Most recently Evans & Sutherland, Inc. revealed a spherical viewing structure which essentially surrounds the user to provide a nearly fully spherical viewing surface. A projected image tracks the user's viewing cone and displays the appropriate scene. An advanced display method being developed by the Human Interface Technology Lab places light directly on the retina of the eye using a weak laser beam. Any of these display systems and their related interfaces can benefit by use of the ODT.

Telepresence

Discussion of a VR system would not be complete without mention of telepresence. While VR system substantially synthesize the user's sensory experience, telepresence systems extract their sensory information from a real, remote source and convey it to the senses of the user. In the simplest example, a pair video cameras might be mounted on a degree-of-freedom platform whose motion is slaved to the user's head. An HMD on the user's head receives the stereo images from the paired video cameras thus creating the visual illusion that the user's head is sitting on the platform instead of the two cameras! A system is this type which also includes sound is commercially available from Telepresence Research, Inc.

With regards to the ODT, it is feasible to couple the walking motion of the user to the lateral movement of a remote sensing device. Using natural walking and turning motion to steer and guide a remote device has the advantage of freeing both hands to perform other tasks rather than being restricted to a steering device like a joystick. A coupling of the telepresent remote with the user would likely include, besides the ODT, a video, a video and sound link. Other system configurations might include one or two hand

operated actuators which the operator uses to preform manipulation tasks at the remote site.

Figures 17a and 17b show a system in which a user at one site, Figure 18a, controls the remote at a distal site, Figure 18b. This advanced form of ODT and telepresent coupling would employ not only the above-mentioned systems, but also a means of conveying the remote's physical orientation. This is accomplished by using the balance cuff 1701 to force the user 1702 into the orientation 1703 of the remote 1704. Feedback on the cuff by the user, in turn, also forces the remote into the orientation of the user. By combining this orientational interplay with a bipedal remote and an exoskeletal structure 1705 which links the remote's legs to the user's legs, it is possible for the remote to balance itself in both standing and walking modes. Combination of the above structures to enable locomotion of the remote is made possible because the user is standing on an ODT active surface 1706 which permits the user to employ their natural balance abilities as they navigate using the electronic eyes of the remote.

Figure 19 is a further modification of the track assembly for an omni directional treadmill indicated generally at 1800 for creating an omni-directional surface on a continuous or endless belt 1801. Belt 1801 is trained about drive rollers 1802 and 1803 powered by motors 1804 and 1805. The relative speeds of motors 1804 and '805 can be adjusted to maintain the upper run of belt 1801 in tension. Motors 1804 and 1805 are reversible electric motors operable to longitudinally move belt 1801 in forward and reverse directions, shown by arrow 1806. A single motor driving worm gears driveably connected to rollers 1802 and 1803 can be used to concurrently drive rollers 1802 and 1803 to selectively move belt 1801 in opposite longitudinal directions.

Belt 1801 comprises a plurality of individual transverse members or segments 1807 positioned side-by-side along the length of belt 1801. As shown in Figure 20, each segment 1807 has an endless transverse belt 1808 trained about cylindrical members or rollers 1809 and 1810. Rollers 1809 and 1810 are rotatably mounted on platform 1813. One of rollers 1809 or 1810 may be attached to platform 1813 through a spring mechanism to maintain tension on the belt. Rollers 1809 and 1810 can be rotatably mounted on endless chains or cables 1811 and 1812 that extend around drive rollers 1802 and 1803. A support platform 1813, coated with a slippery material, such as Teflon, is located below the upper run of belt 1808. Belt 1808 is free to ride on platform 1813 and support a person walking or running on belt 1801. Platform 1813 has opposite ends rotatably supporting rollers 1809 and 1810 to maintain the spacing between the rollers.

The lower run of belt 1808 is located in driving engagement with a plurality of wheel assemblies 1814, 1815, and 1817. An example of the detailed structure of a wheel assembly is shown in Figure 11. A motor 1818 concurrently rotates all wheel assemblies to transversely drive belt 1808 in selected opposite directions and at regulated speeds. Three wheel assemblies 1814, 1816, and 1817 are shown in driving contact with belt 1808. Additional wheel assemblies can be used to support and drive the lower run of belt 1808. the wheel assemblies 1814, 1816 and 1817 are vector slip wheels that permit actuation about the central axis of the wheel while permitting transverse motion about the central axis due to the motions of the multiple rollers or sleeve places around each wheel. These rollers are free to rotate about each of their own axis. Support of individual rollers by vector slip wheels permits free movement of belt 1808 along the Y direction, and permits powering the belt 1808 in the X direction by actively

powering one or more vector slip wheels which, in turn, convey their rotary motion to the linear motion of the belt 1808 through generally frictional contact with that belt. Opposite each wheel assembly 1814, 1815 and 1817 are a pair of idler rollers 1820 and 1821 which permit relatively frictionless conveyance of shear force between the wheel assembly and belt 1808.

As shown in Figure 21, platform 1813 is an inverted U-shaped or channel member having a flat top surface for supporting the upper run of belt 1808. The idler rollers 1821 are journaled to the downwardly extended side walls of platform 1813. The bottom run of belt 1808 rides on idler rollers 1821 during transverse movement of belt 1808 upon rotation of vector thrust wheels 1814, 1816 and 1817. Adjacent platforms are articulately connected with hinges 1822 and 1823 to allow the belt assembly 1801 to move around drive rollers 1802 and 1803.

Belt 1808 moves transversely or perpendicular to the direction of movement of belt 1801. By simultaneous motions of belts 1801 and 1808, the active surface or top of belt 1801 is able to provide motion in any direction through the vector sum of individual X and Y motions as illustrated at 1819 in Figure 19. The advantages of omni-directions treadmill 1800 include a minimum number of parts and less weight than roller belt treadmills. The treadmill is economical to fabricate and can be assembled in a reasonable period to time. It is durable and reliable in operation to provide a large active surface that is effectively movable in all two dimensional directions.

Another embodiment of the omni-directional treadmill mechanism indicated generally at 1900 is shown in Figure 23 to 24. A first belt 1901 has a plurality of rollers 1902 rotatably mounted on U-shaped cradles 1903. Cradles 1903 are connected with longitudinal pivot members or pins into an endless belt having a

plurality of rollers 1902. Adjacent rollers 1902 overlap each other as shown in Figure 22. Belt 1901 is mounted on a support endless belt that is trained over longitudinal drive rollers journeyed on a frame. A motor connected to at least one drive roller operates to transversely move support belt and belt 1901. Each roller 1902 has circumferential teeth 1904 shown in Figure 24. The teeth 1904 extend circumferentally around the roller. The cradles 1903 are captured or attached to the endless support belt that is powered in a transverse direction in response to a control that responses to movements of the user.

A second belt 1906 has a plurality of longitudinal orientated rollers 1907. Each roller 1907 is rotatably mounted on a longitudinal rod 1908. Opposite ends of each rod 1908 are turned about transverse rods 1909 and 1910. This locates rollers 1907 side-by-side each other in transverse rows. The rods 1909 and 1910 pivotally connect the transverse rows of rollers 1907 to form the endless second belt 1906. Opposite ends of belt 1906 are trained over transversal rollers or drums. At least one roller is power driven with a motor coupled to the control. The control selectively operates the motors for the first and second belts in response to movement of the user on the active surface of the first belt. As shown in Figure 24, roller 1907 has longitudinal teeth 1911 that engage the teeth 1904 of roller 1902. Transverse movement of the first belt 1901 causes rollers 1907 to rotate on rods 1908. In use, the lower rollers 1902 frictionally contact the lower portion of upper rollers 1907, conveying their Y motion by ignoring any X motion component. The upper rollers 1907 pass through the Y motion from the lower or first belt 1901 and contribute their own X motion. The second belt 1906 moving in the X direction contributes to the surface motion vector in the X direction only. The first belt 1901 with cradled

rollers 1902 contributes to the surface motion vector in the Y direction only. Combined motion of the two belts 1901 and 1906 permits creation of a complete circle of motion vectors.

Figure 23 shows a more detailed description of the interaction of two individual rollers 1902 and 1907 of the mechanism. A roller belt roller 1907 traveling with velocity V in the X direction 1902 and 1907 has velocity V in the minus Y direction. Linear action of the upper roller in the X direction is passed without friction by the supportive lower roller, and causes the lower roller to rotate about its axis. At the same time, the lower roller actively powers the upper roller 1907 so that it rotates about its own axis.

Choosing a global coordinate system with 0, 0, 0 at point 1912 we see that the point has a combined surface vector set which is the combination of the linear action in X and the rotary action about X. In the Vector Detail we see that the instantaneous velocity, V, of 1912 is the vector sum of linear velocity V and the rotationally transferred linear velocity V, now reversed in direction.

The entire contact line along X at the top of the upper roller contains the required vector set which produces vector V. All the other rollers comprising the upper surface of the roller belt contain this vector set as well.

Since the contact lines at the top of each roller 1907 are moving in concert, a mass resting on the active surface defined by the sum of the contact lines is moved in the direction of the combined X and Y motion vectors.

A roller-belt ODT design is readily manufacturable, easily powered, and relatively compact.

Since the basic mechanism permits line contact at the active surface, and the lines are minimally spaced on the order of 1.5cm, and since each contact

line contains both X and Y vector components, there are few restrictions on the types of loading or the nature of the load's contact surface. A user will be able to crawl as well as walk. A shoe with a waffled sole design will fare as well as a flat-bottomed loafer.

The treadmill mechanism 1900 works in synchrony with the VR system by sending velocity and direction signals to the image generation computer. The computer uses the velocity vector thus provided to update the image which is shown to the user so that the user sees a visual image which takes into account this vector. For example, if the user's velocity is 1/2 meter/sec in the X direction as indicated by the X direction motion of the treadmill, the user will observe objects within the virtual world passing by at 1/2 meter/sec in the minus X direction.

CLAIMS

1. An apparatus for allowing a user to walk or run in any arbitrary direction comprising: a frame, a track assembly mounted on the frame, said track assembly having a user active surface means for supporting the user walking or running thereon, wherein said user active surface means having a first user support means moveable in a first direction for supporting the user and a second user support means movable in a second direction, said first user support means having a plurality of user support members rotatable -about axes generally parallel to the first direction, first drive means connected to the user support members to move said user support members in the first direction, and second drive means cooperating with said second user support means to rotate said second user support means in the second direction, whereby the combined movements of the user support members and rotation of the second user support means results in omni-directional user movement, and control means responsive to directional orientation of the user of the user active surface means to selectively control the operation of the first and second drive means, thereby control the directional user movement to conform with the orientation of the user on the user active surface means.

2. The apparatus of claim 1, wherein the user support members are cylindrical members, at least one cylindrical member being connected to the first drive means to rotate there cylindrical member, and said first user support means further comprises endless means trained about said cylindrical members and moveable by the one cylindrical member in said first direction, said endless means having rod means for rotatable supporting the user support members for rotation about axes generally parallel to the first direction of movement of the first user support means.

3. The apparatus of claim 2, wherein the second user support means comprises a pair of rollers and an endless belt trained about said rollers, said second drive means being connected to at one of the rollers, said second drive means being connected to at one of the rollers to move the endless belt, said endless belt having a top surface operably engageable with the user support members to rotate said user support members.

4. The apparatus of claim 3, wherein said second user support means further comprises a support surface, and wherein said endless belt has an upper run having said top surface, and said support surface located below said upper run for holding the upper run in contiguous relationship relative to the user support members.

5. The apparatus of claim 1, wherein the first user support means further includes rods, and wherein the user support members are cylindrical sleeves rotatably mounted on the rods.

6. The apparatus of claim 1, wherein the first user support means further includes a plurality of longitudinal rods, and wherein the user support members are spherical members rotatably mounted on the rods for rotation about the longitudinal axes of the rods.

7. The apparatus of claim 1, wherein the control means includes a closed loop position control to maintain position of the user toward the center of the user active surface means in response to user traversal of the user active surface means.

8. The apparatus of claim 1, wherein the control means includes adapting means adapted to be coupled with the user to actively track the motion of the user and to assist the user in maintaining the balance.

9. The apparatus of claim 8, wherein the adapting means adapted to be coupled with the user includes a cuff connectable to the user.

10. The apparatus of claim 8, wherein the adapting means adapted to be coupled with the user includes handle means adapted to be grasped by the user to assist the user in maintaining the balance.

11. An omni-directional treadmill for allowing a user to walk or run in any arbitrary direction comprising: a frame, a track assembly mounted on the frame, said track assembly having a user active surface means for supporting the user walking or running thereon, wherein said user active surface means having a first user support means moveable in a first direction for supporting the user and a second user support means movable in a second direction, said first user support means including a plurality of user support members rotatable about axes generally parallel to the first direction, first drive means connected to the user support members to move said user support members in the first direction, and second drive means cooperating with said second user support means to rotate said second user support means in the second direction, whereby the combined movements of the user support members and rotation of the second user support means results in omni-directional movement of the user on the user active surface means in a second direction, and control means including virtual reality means responsive to directional orientation of the user on the user active surface means to selectively control the operation of the first and second drive means and to provide the virtual reality response corresponding to the direction of the movement of the user on the user active surface means, thereby control the directional user movement to conform with the orientation of the user on the user active surface means.

12. The treadmill of claim 11, wherein the user support members are a pair of cylindrical members, at least one cylindrical member being connected to the first drive means to rotate the one cylindrical member, and said first user support means further comprises endless means trained about said cylindrical members and moveable by the one cylindrical member in said first direction, said endless means having rod means for rotatably supporting the user support members for rotation about axes generally parallel to the first direction of movement of the first user support means.

13. The treadmill of claim 12, wherein the second user support means comprises a pair of rollers and an endless belt trained about said rollers, said second drive means being connected to at least one of the rollers to move the endless belt, said endless belt having a top surface operably engageable with the user support members to rotate said user support members.

14. The treadmill of claim 13, wherein said second user support means further comprises a support surface, and wherein said endless belt has an upper run having said top surface, and said support surface located below said upper run for holding the upper run in contiguous relationship relative to the user support member.

15. The treadmill of claim 11, wherein the first user support means further includes rods, and wherein the user support members are cylindrical sleeves rotatably mounted on the rods.

16. The treadmill of claim 11, wherein the first user support means further includes a plurality of longitudinal rods, and wherein the user support members are spherical members rotatably mounted on the rods for rotation about the longitudinal axes of the rods.

17. The treadmill of claim 11, wherein said virtual reality means includes a head-mounted visual display for displaying visual images, a display control

means for projection of said visual images,speaker means for generating sounds, a microphone for the user, means for sensing the position of the user on the user active surface means and means for connecting the head-mounted visual display, display control means and speaker means for generating images an sounds.

18. The treadmill of claim 17, wherein said virtual reality means further includes interactive solids for providing the user with haptic feedback.

19. The apparatus of claim 1, wherein said control means includes virtual reality means responsive to directional orientation of the user on the user active surface means, said virtual reality means includes a visual display for displaying visual images, a display control means for projection of said visual images, speaker means for generating sounds, a microphone for the user, means for sensing the position of the user on the user active surface means and means for connecting the head-mounted visual display, display control means and speaker means for generating images and sounds, respectively.

20. The apparatus of claim 19, wherein said virtual reality means further includes interactive solids for providing the user with haptic feedback.

21. An apparatus for allowing a user to walk or run in any arbitrary direction having a frame, a track assembly mounted on the frame, the track assembly having a user active surface means for supporting the user walking or running thereon characterized by the user active surface means having a plurality of side-by-side endless first belts, sleeve means for accommodating opposite ends of the first belts whereby the first belts can be moved around the sleeve means, support means for each first belt located between the sleeve means, means for pivotally connecting adjacent support means to provide an endless second belt, roller means mounted on the frame supporting opposite ends of the second belt,

first drive, means for rotating at least one of the roller means to move the second belt in a first direction, and second drive means for moving the second belt in a second direction whereby the combined movements of the first and second belts results in omni-directional user movement of the active surface means, and controls means responsive to directional orientation of the user of the users active surface means to selectively control the operation of the first and second drive means thereby control the directional user movement to conform with the orientation of the user on the user active surface means.

22. The apparatus of claim 21, wherein the support means for each first belt comprises an inverted U-shaped member having a generally flat top surface for supporting the upper run of the first belt, side means including hinge means articulately coupling adjacent portions of the inverted U-shaped member.

23. The apparatus of claim 21, including idler rollers mounted on the support means engageable with the bottom runs with the first belts, said second drive means being engageable with the second belts to hold the bottom run of the first belts in engagement with the idler rollers.

24. The apparatus of claims 21 or 23, wherein the second drive means include vector thrust wheels engageable with the second belts, and means for rotating said wheels thereby moving the second belts in the second direction.

25. The apparatus of claim 21, wherein the control means includes a closed loop position control to maintain position of the user toward the center of the user active surface means in response to user traversal of the user active surface means.

26. The apparatus of claim 21, wherein the control means includes adapting means adapted to be coupled with the user to actively track the motion of the user and to assist the user in maintaining the balance.

27. The apparatus of claim 26, wherein the adapting means adapted to be coupled with the user includes a cuff connectable to the user.

28. The apparatus of claim 26, wherein the adapting means adapted to be coupled with the user includes handle means adapted to be grasped by the user to assist the user in maintaining the balance.

29. The apparatus of claims 21, 25, 26, or 18, wherein the control means includes virtual reality means responsive to directional orientation of the user on the user active surface means, said virtual reality means having a visual display for displaying visual images, a display control means for projection of the visual images, speaker means for generating audible sounds, a microphone for the user, means for sensing the position of the user on the user active surface means, and means for connecting the visual display, display control means and speaker means for generating images and sounds, respectively.

30. The apparatus of claim 29, wherein said virtual reality means further includes interactive solids for providing the user with haptic feedback.

31. The apparatus of all preceding claims, wherein the control means includes force feedback means operable to apply an external force to the user.

32. A track assembly for an omni-directional treadmill for allowing a user to walk or run in any arbitrary direction comprising: user active surface means for supporting the user walking or running thereon, said user active surface means having a plurality of side-by-side endless first belts, sleeve means for accommodating opposite ends of the first belts

whereby the first belts can be moved in a transverse direction around the sleeve means, support means for each first belt located between the sleeve means, means for pivotally connecting adjacent support means to provide an endless section belt assembly, roller means supporting opposite ends of the second belt assembly for movement in a longitudinal direction, first drive means for moving the second belt assembly in said longitudinal direction, second drive means for moving the second belts in the transverse direction whereby the combined movement of the first belt assembly and second belts results in omni-directional user movement of the active surface means, and control means responsive to direction orientation of the user of the user active surface means to selectively control the operation of the first and second drive means thereby control the directional user movement to conform with the orientation of the user on the user active surface means.

33. The track assembly of claim 32, wherein the support means for each first belt comprises an inverted U-shaped member having a generally flat top surface for supporting the upper run of the first belt, side means including hinge means articulately coupling adjacent portions of the inverted U-shaped member.

34. The track assembly of claim 32, including idl~~er roll~~ers mounted on the support means engageable with the bottom runs with the first belts, ~~said~~ second drive means being engageable with the second belts to hold the bottom run of the first belts in engagement with the idler rollers.

35. The track assembly of claims 32 or 34, wherein the second drive means include vector thrust wheels engageable with the second belts, and means for rotating said wheels thereby moving the second belts in the second direction.

36. The track assembly of claim 32, wherein the control means includes a closed loop position control to maintain position of the user toward the center of the user active surface means in response to user traversal of the user active surface means.

37. The track assembly of claim 32, wherein the control means includes adapting means adapted to be coupled with the user to actively track the motion of the user and to assist the user in maintaining the balance.

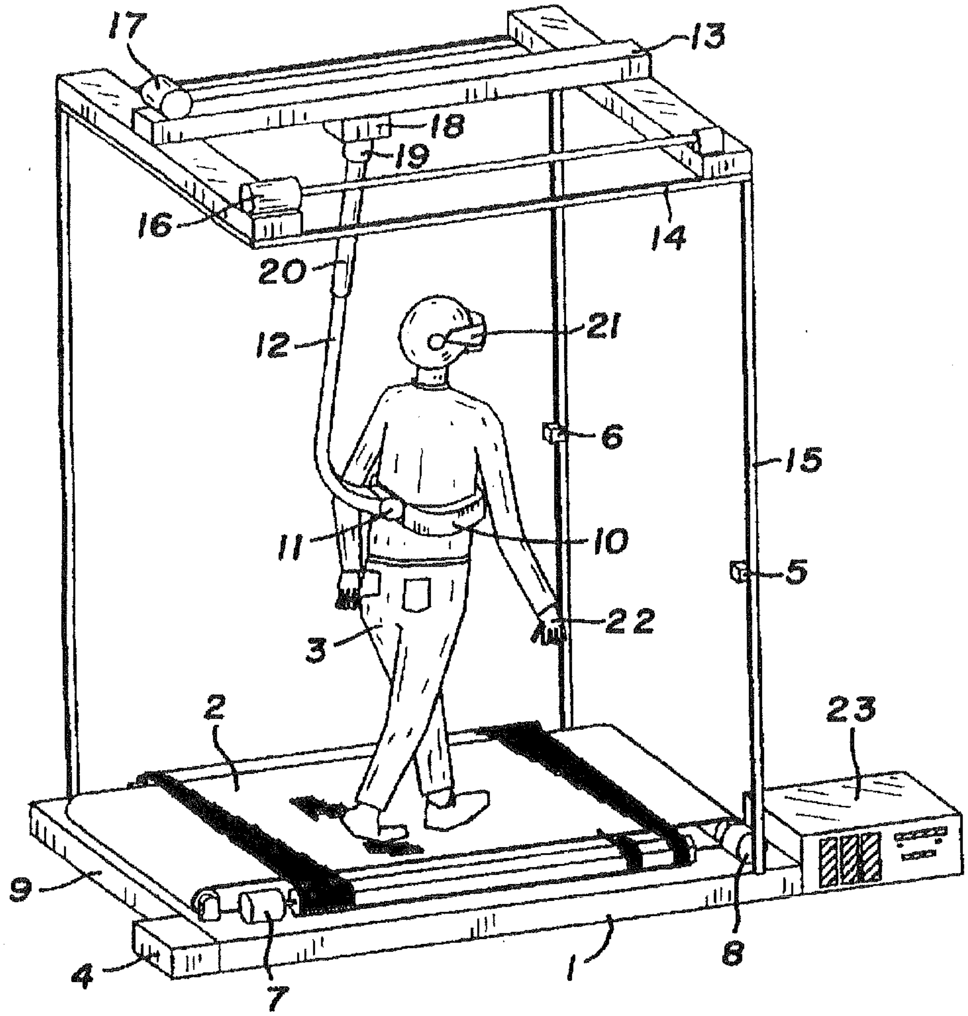
38. The track assembly of claim 32, wherein the adapting means adapted to be coupled with the user includes a cuff connectable to the user.

39. The track assembly of claim 37, wherein the adapting means adapted to be coupled with the user includes handle means adapted to be grasped by the user to assist the user in maintaining the balance.

40. The apparatus of claims 32, 36, 37, 38 or 39, wherein the control means includes virtual reality means responsive to directional orientation of the user on the user active surface means, said virtual reality means having a visual display for displaying visual images, a display control means for projection of the visual images, speaker means for generating audible sounds, a microphone for the user, means for sensing the position of the user on the user active surface means, and means for connecting the visual display, display control means and speaker means for generating images and sounds, respectively.

41. The track assembly of claim 40, wherein said virtual reality means further includes interactive solids for providing the user with haptic feedback.

42. The track assembly of each of claims 32 to 41, wherein the control means includes force feedback means operable to apply an external force to the user.


17
13
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11
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5
22
3
2
23
9
8
4
7
1

FIG.1

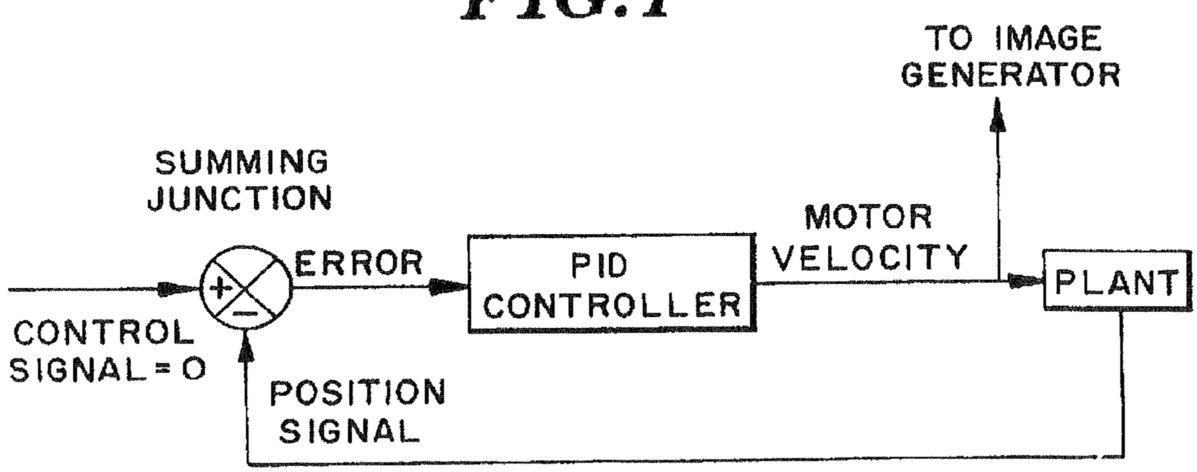

TO IMAGE GENERATOR
SUMMING JUNCTION
MOTOR VELOCITY
ERROR
PID CONTROLLER
PLANT
CONTROL SIGNAL = O
POSITION SIGNAL

FIG.2

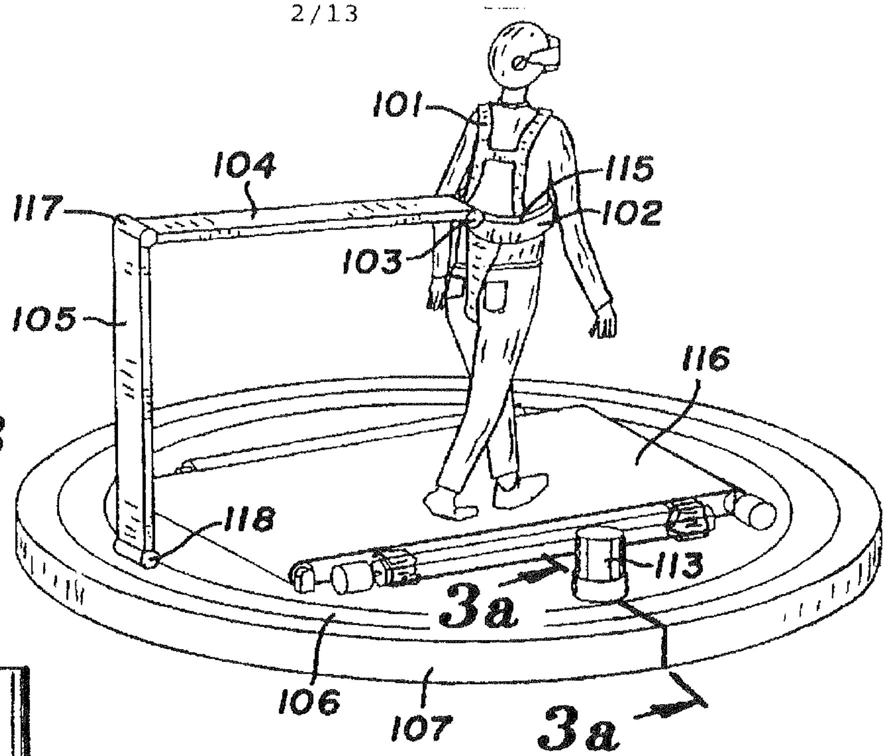


FIG.3

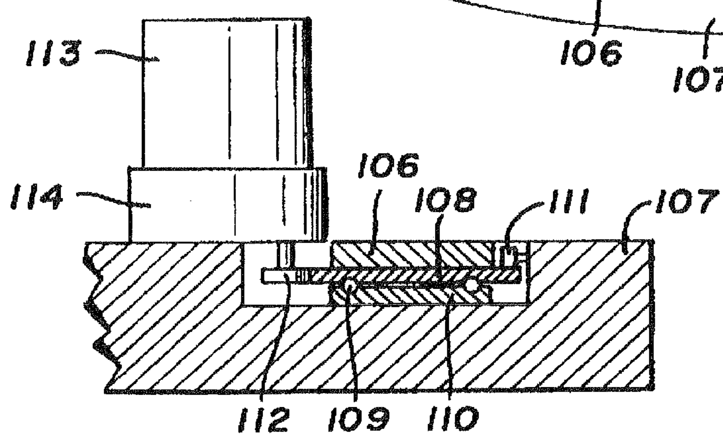


FIG.3a

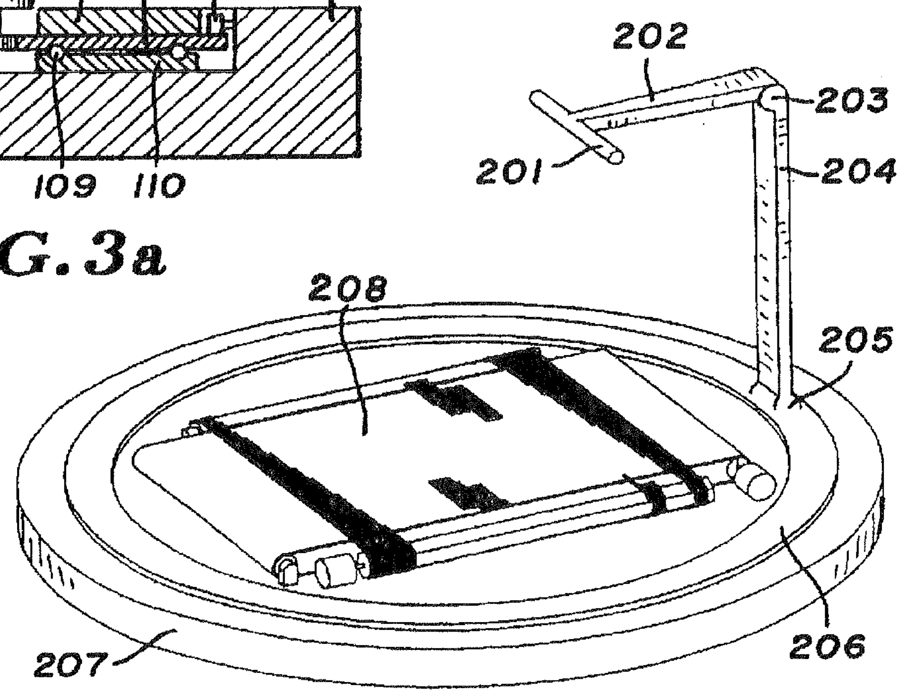


FIG.4

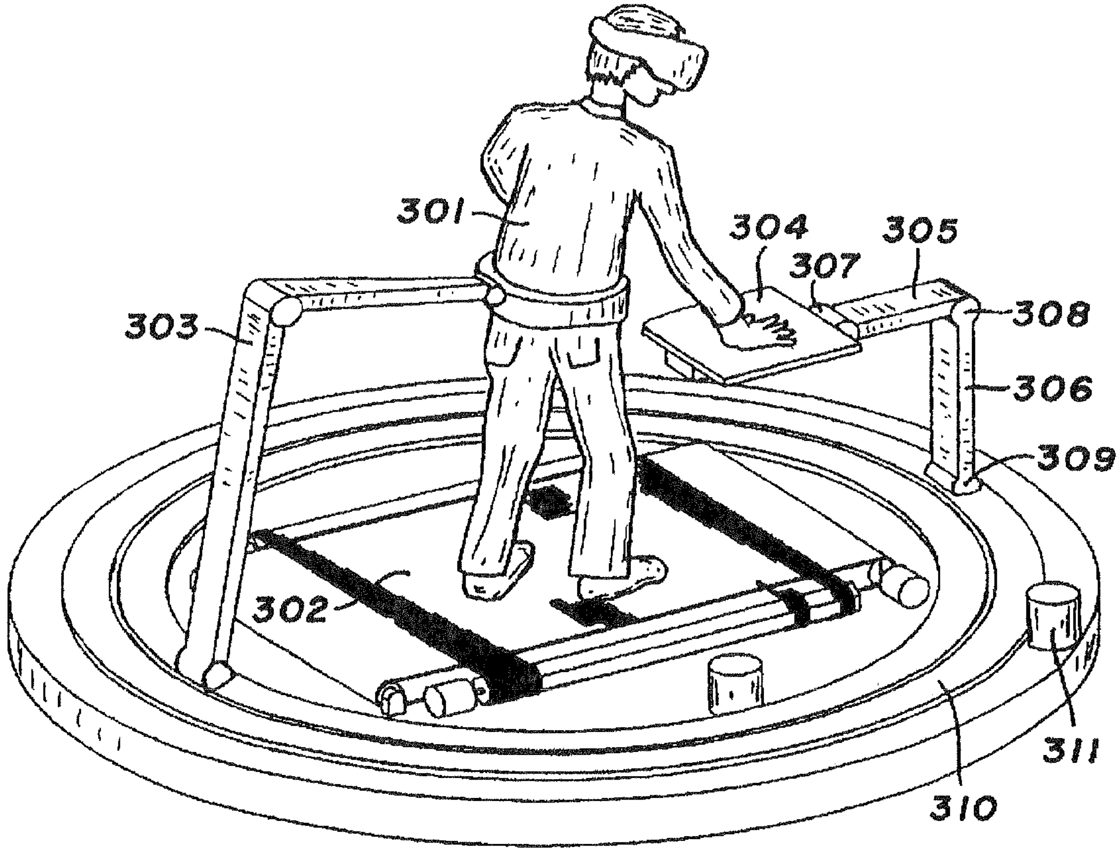


FIG. 5a

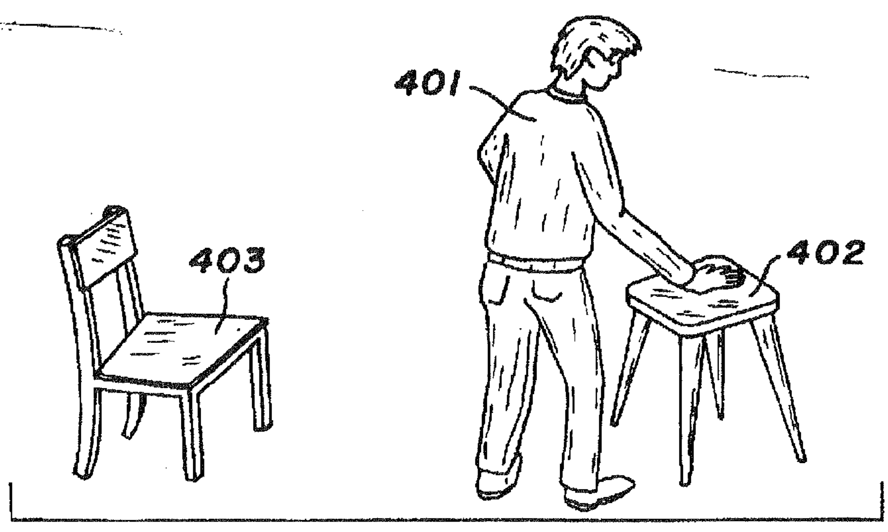


FIG. 5b

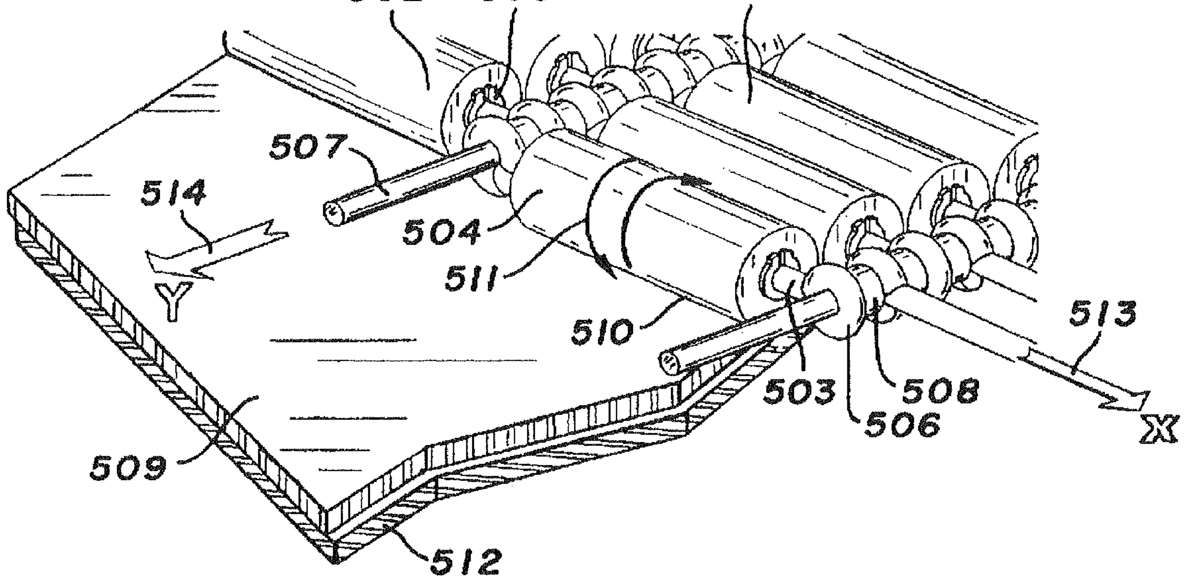

502
505
501
507
514
Y
504
511
510
513
503
508
506
X
509
512

FIG.6

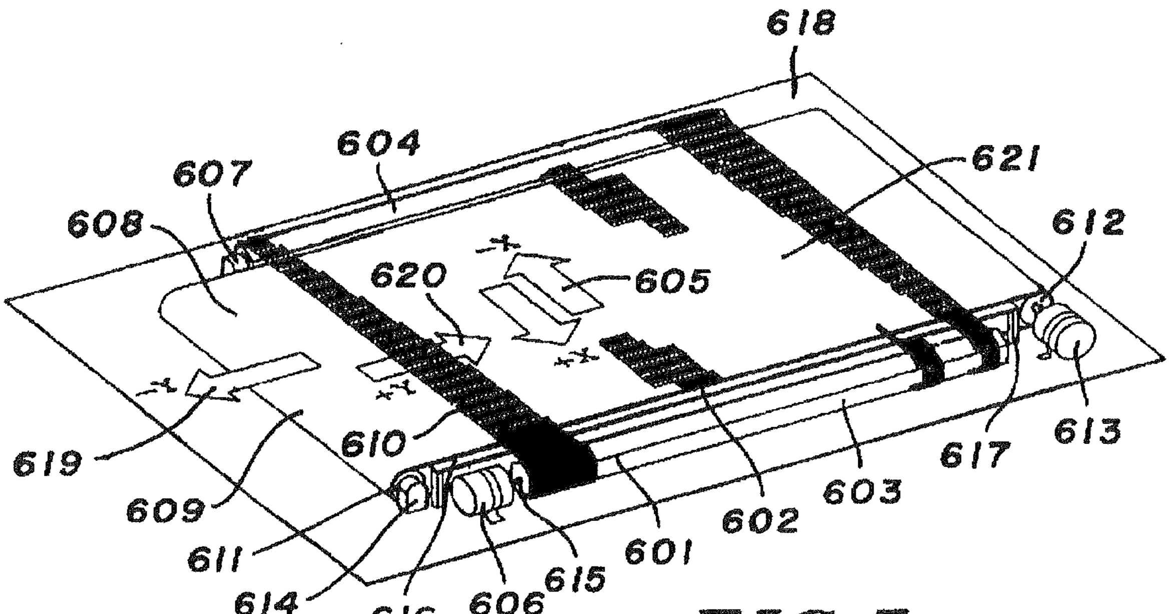

618
604
621
607
608
612
620
605
-X
+X
-Y
+Y
619
610
613
617
609
603
602
611
601
614
616
606
615

FIG.7

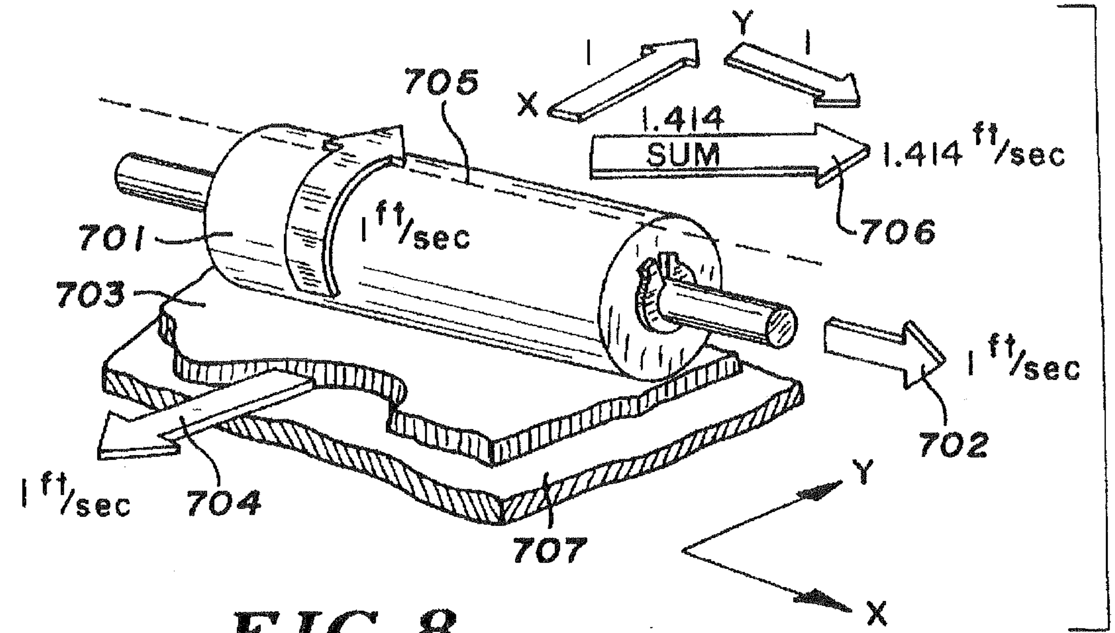
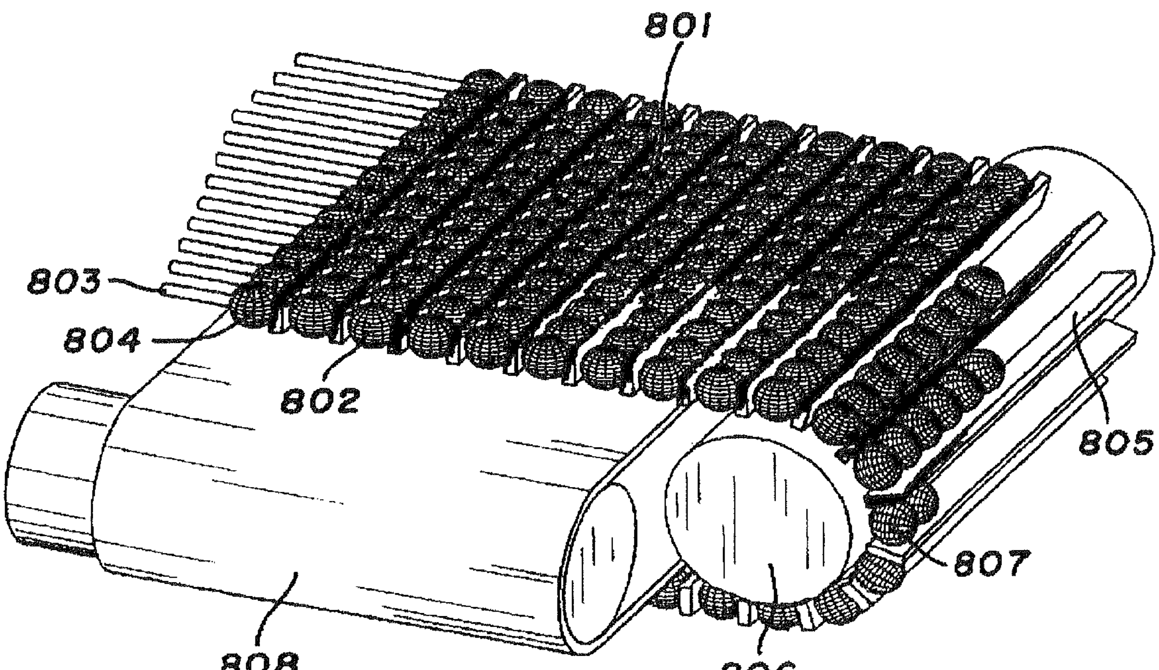

705
X
I
Y
I
1.414
SUM
1.414 ft/sec
706
701
1 ft/sec
703
702
1 ft/sec
1 ft/sec
704
707
Y
X

FIG.8


801
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804
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806

FIG.9

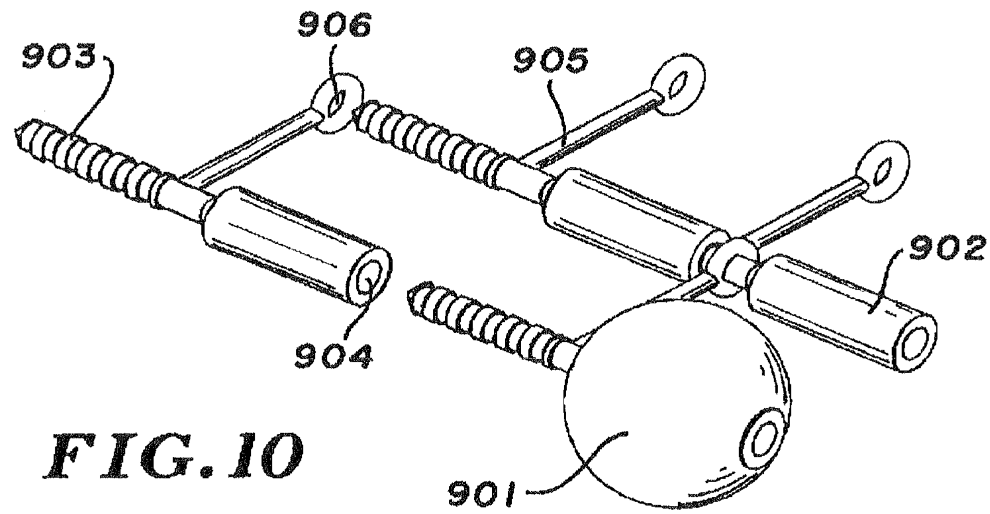


FIG. 10

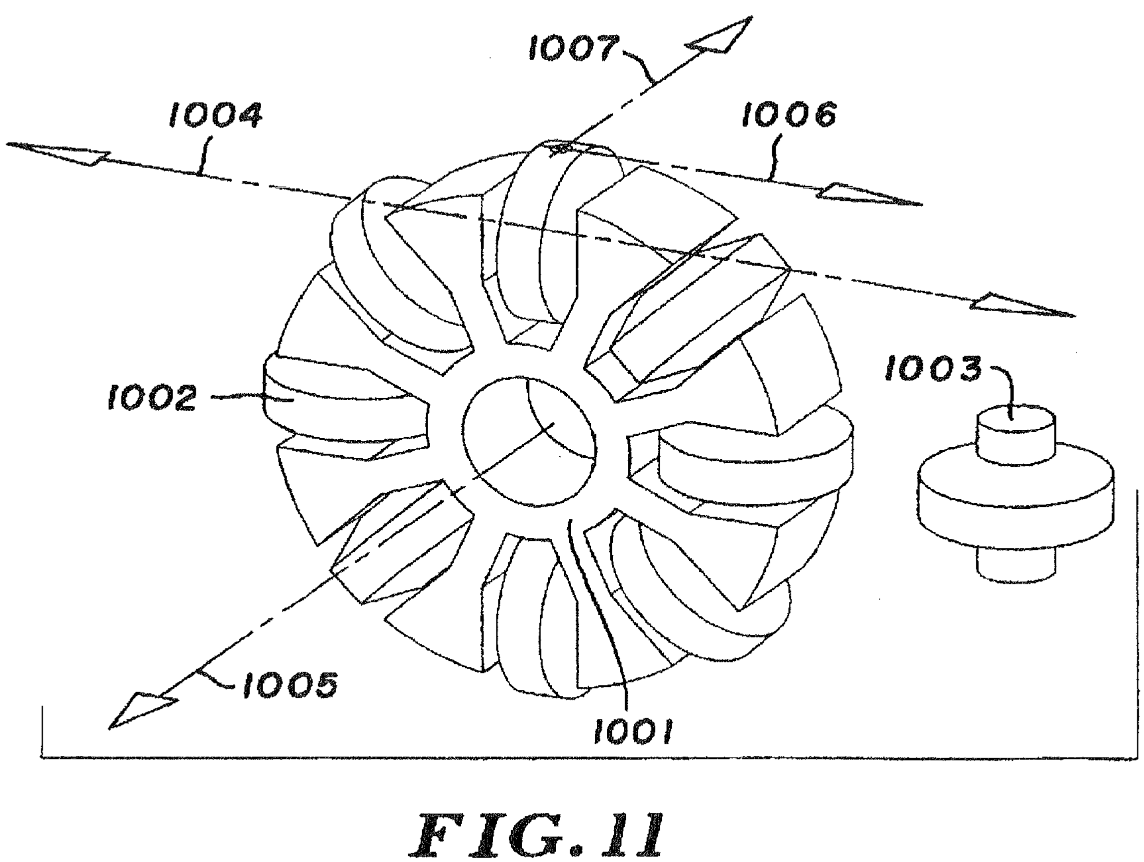


FIG. 11

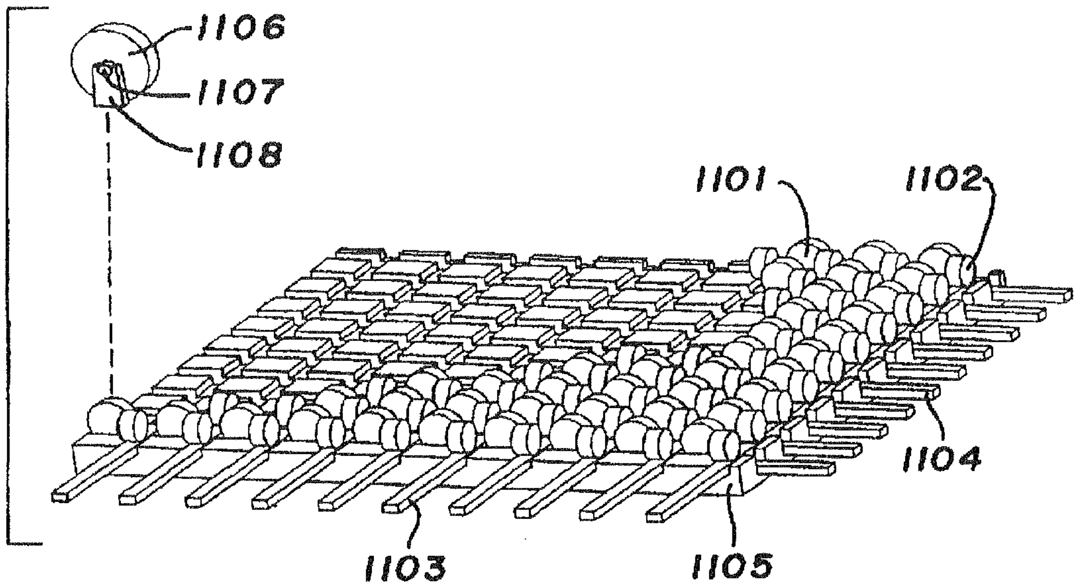


FIG. 12

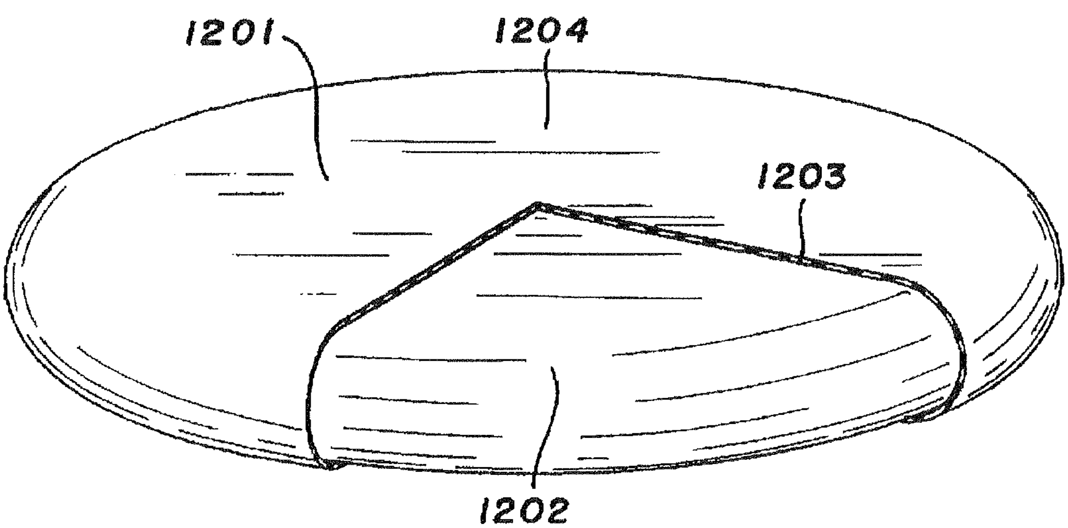
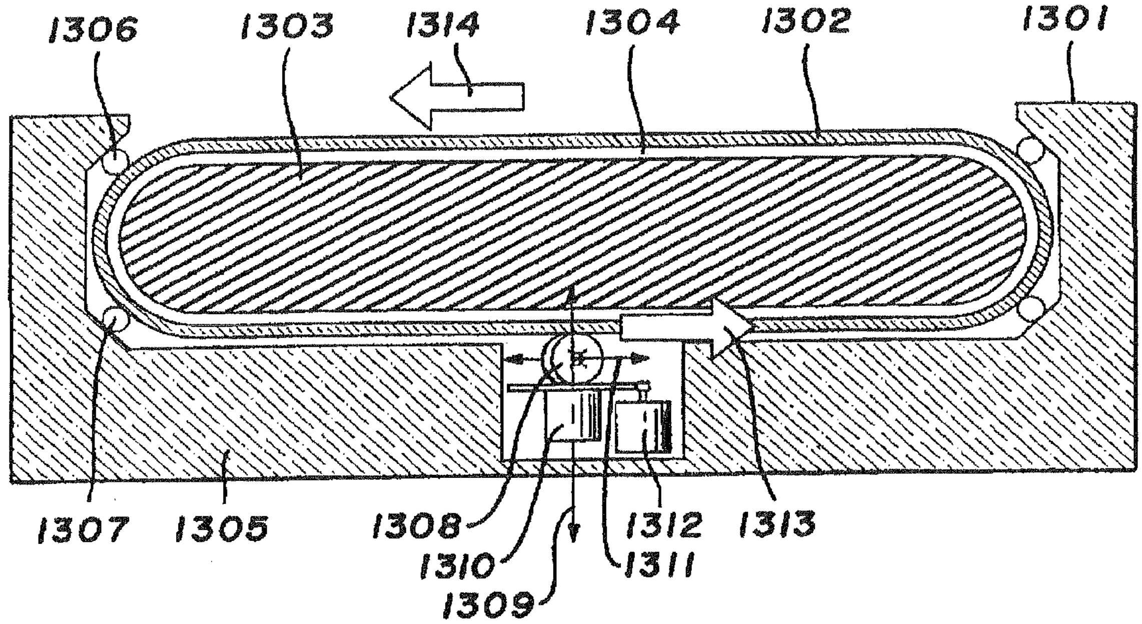


FIG. 13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1303
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1301
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1313

FIG. 14

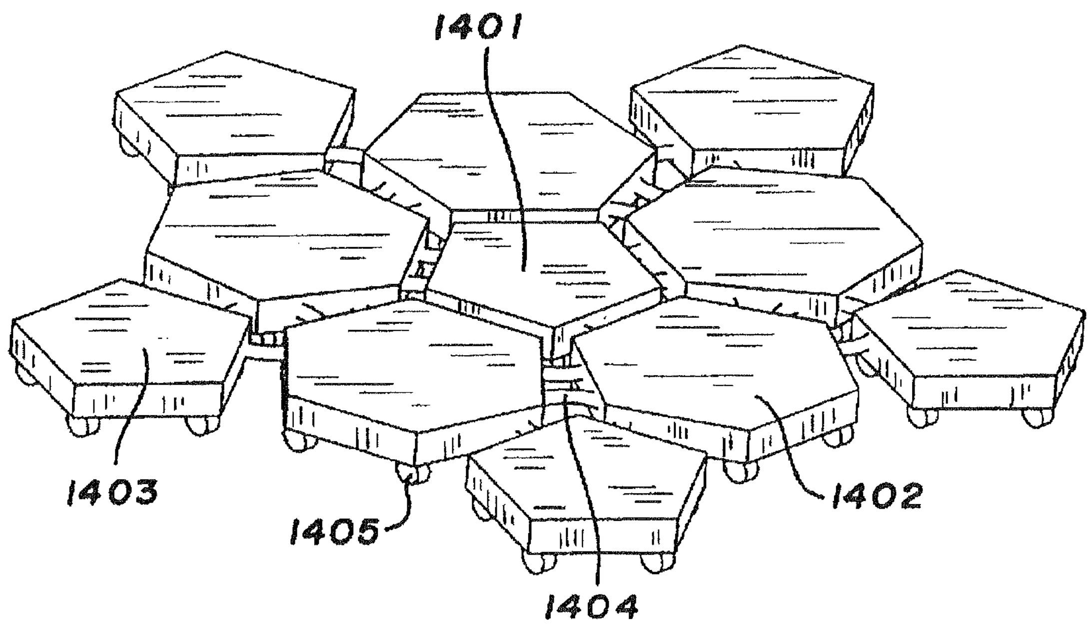

1401
1403
1405
1404
1402

FIG. 15

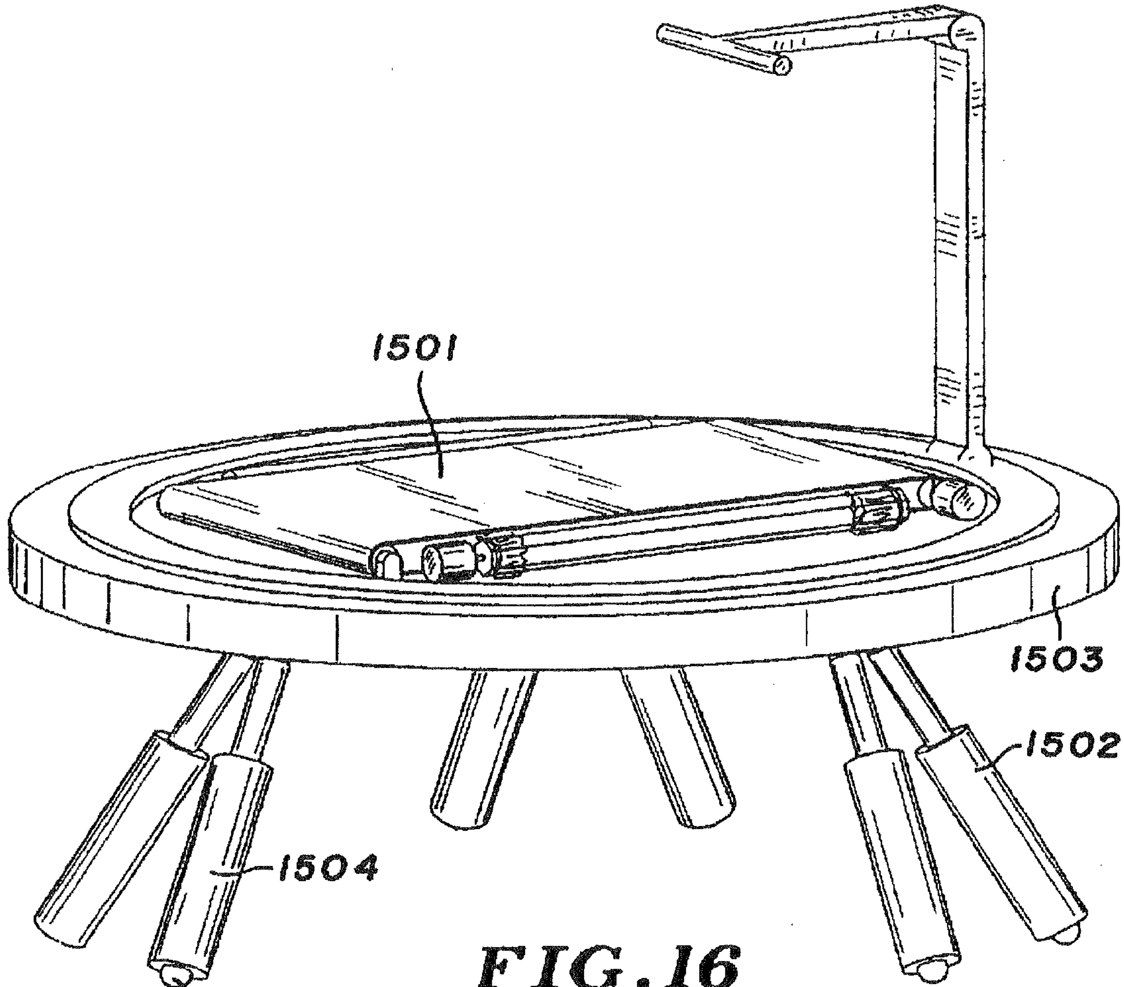


FIG. 16

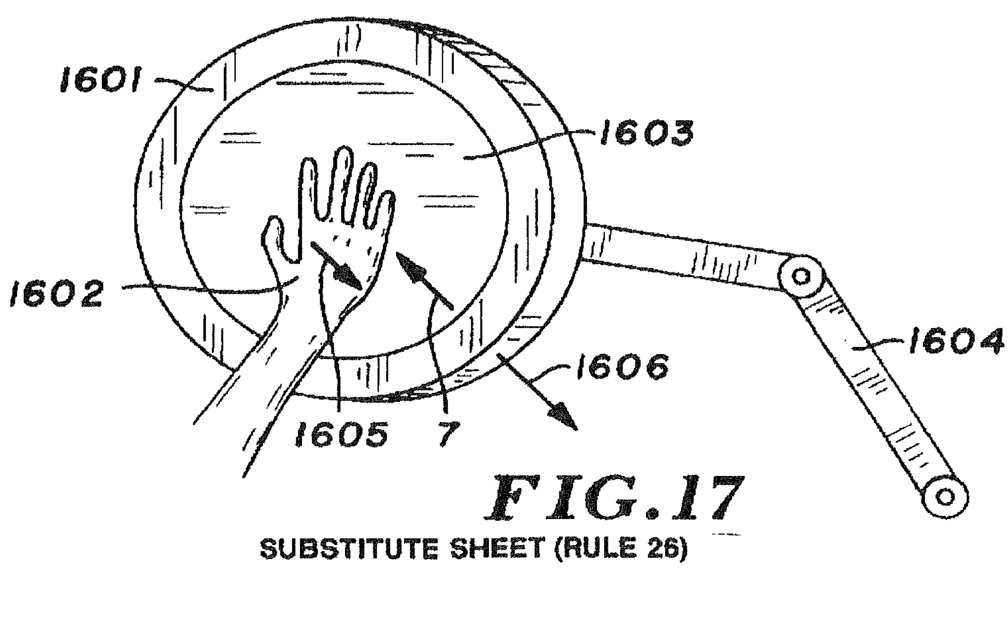


FIG. 17

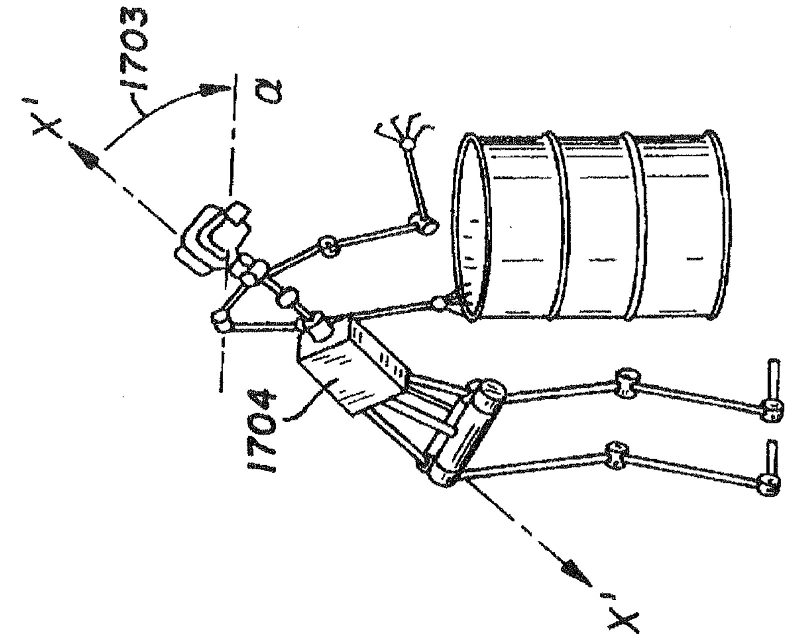


FIG. 18b

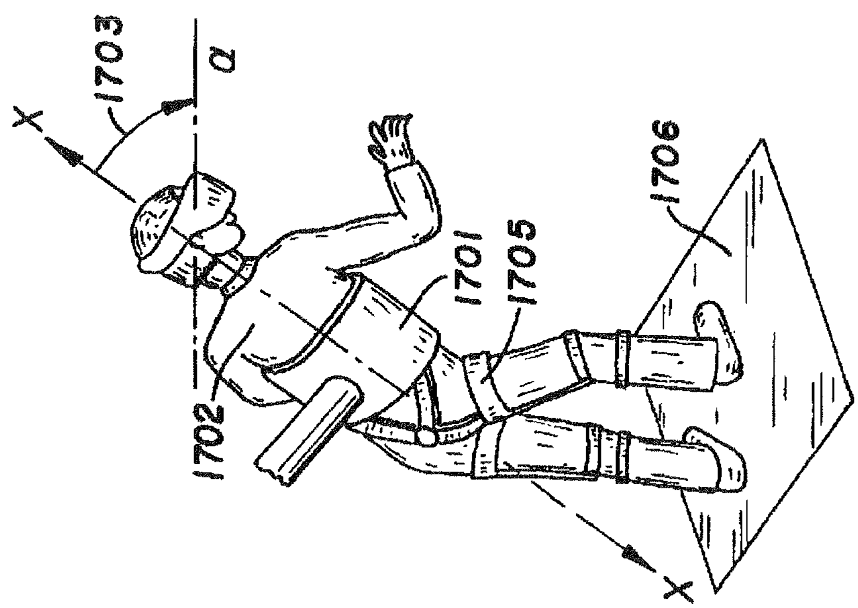


FIG. 18a

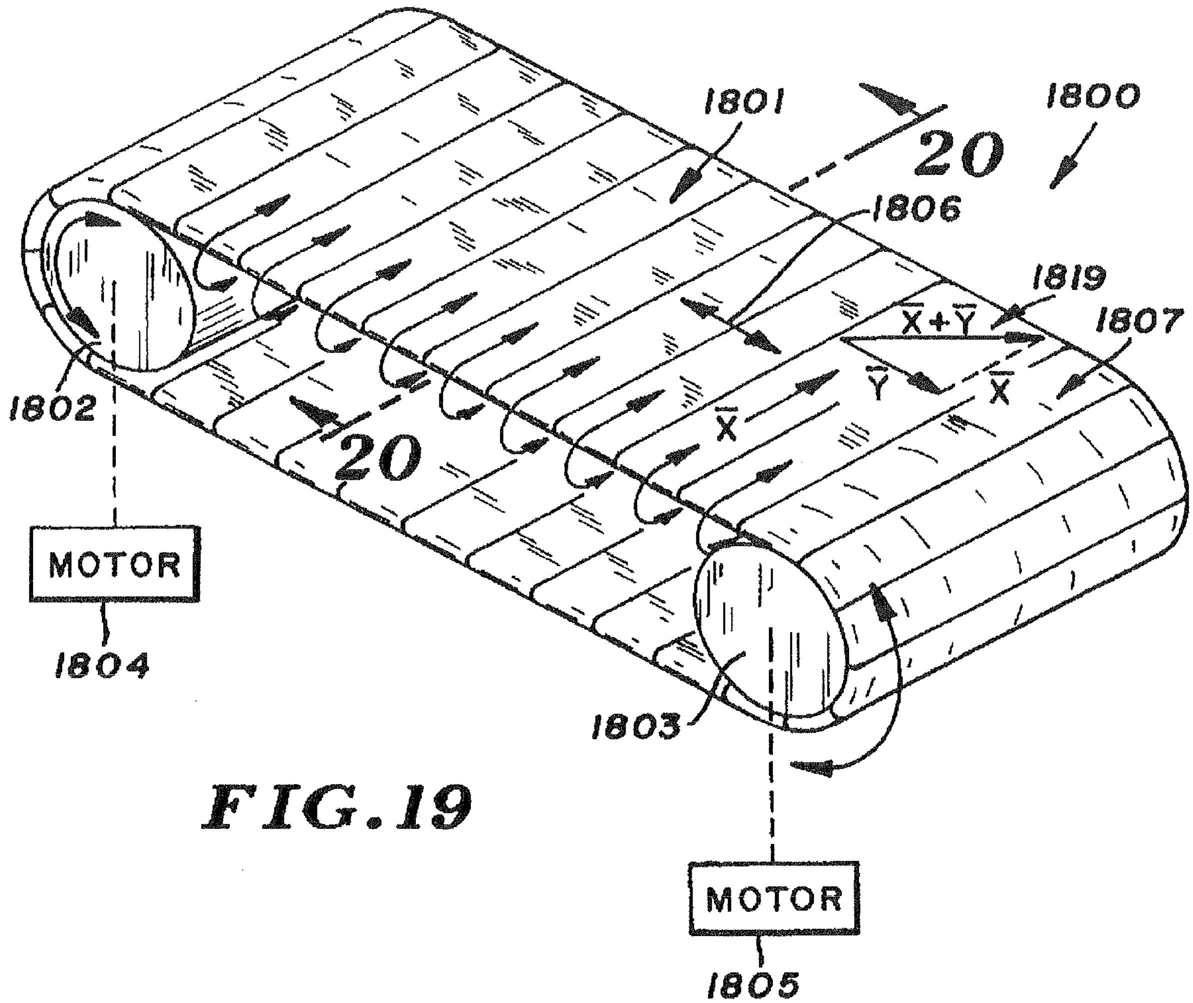
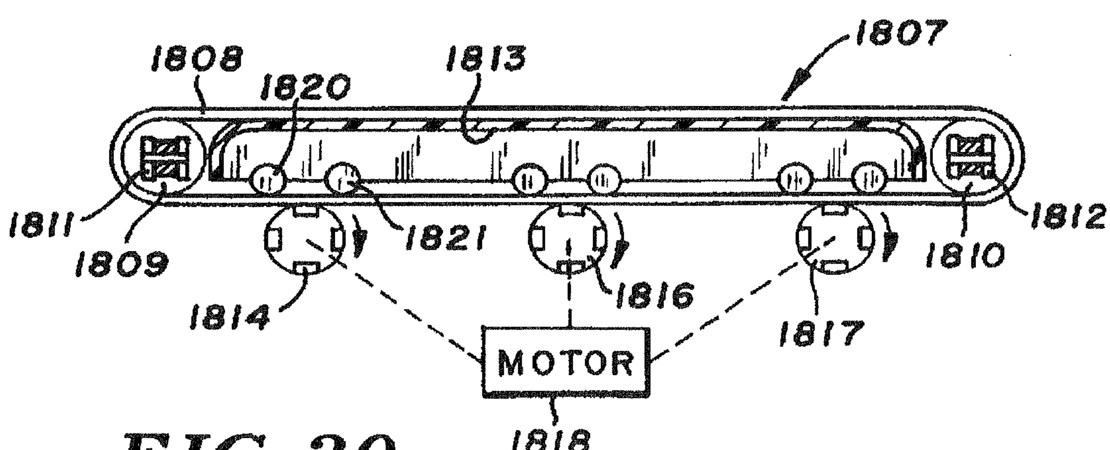

1801
1800
20
1806
1819
$\bar{X}+\bar{Y}$
1807
$\bar{Y}$
$\bar{X}$
$\bar{X}$
1802
20
MOTOR
1804
1803
MOTOR
1805

FIG. 19


1807
1808
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1810
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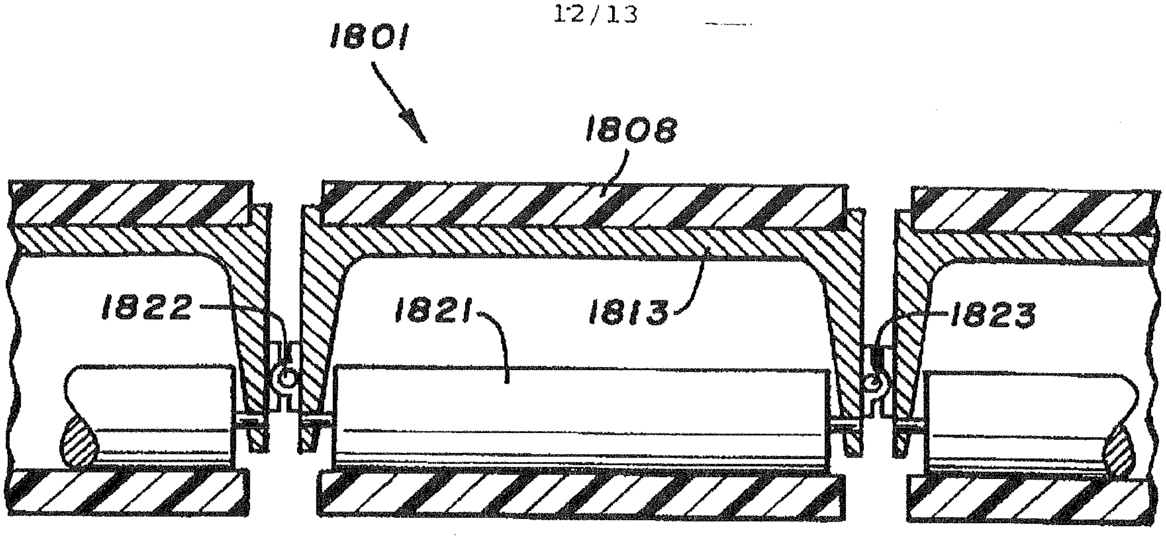
1817
MOTOR
1818

FIG. 20


1801
1808
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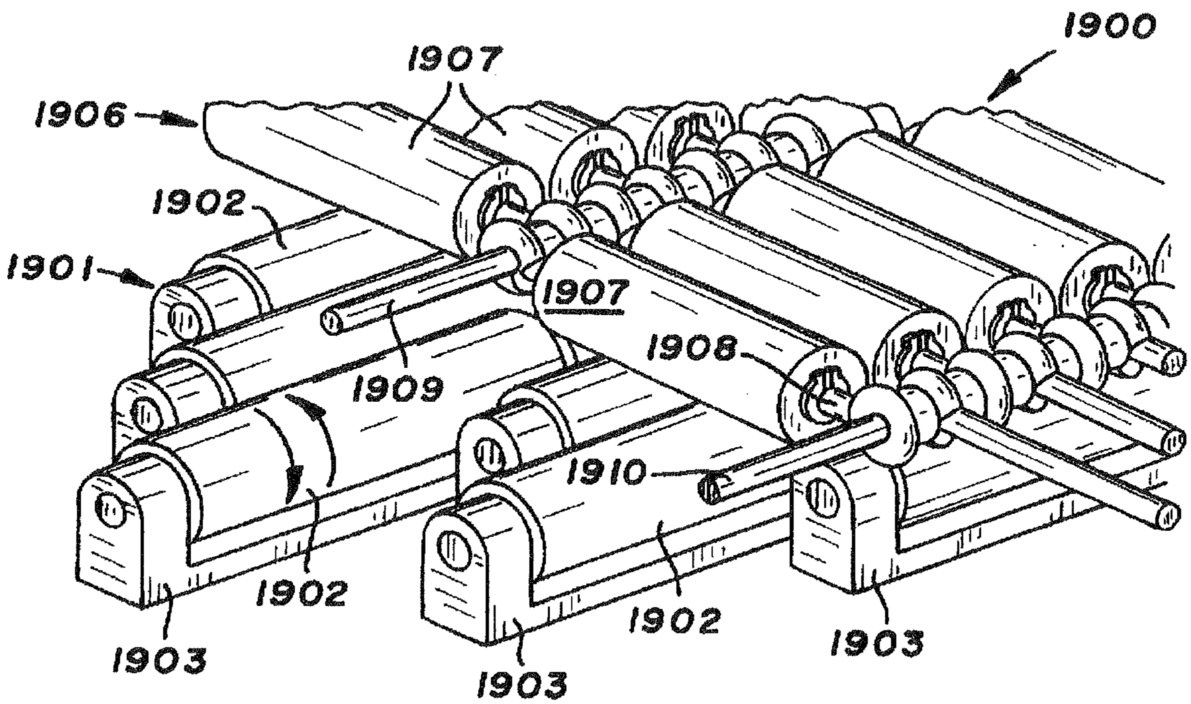
1823

FIG. 21


1900
1907
1906
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1903

FIG. 22

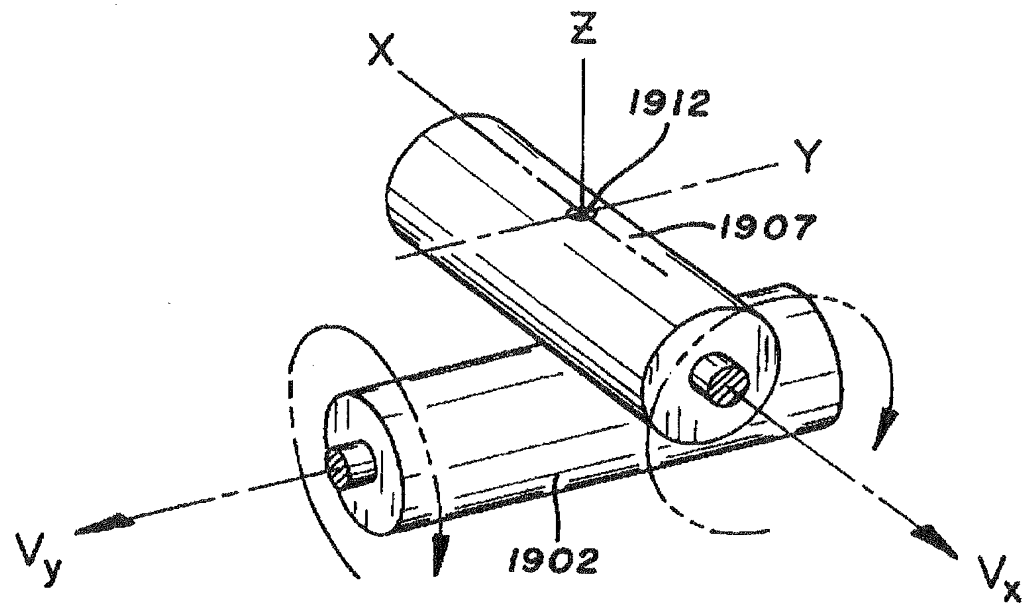

FIG. 23

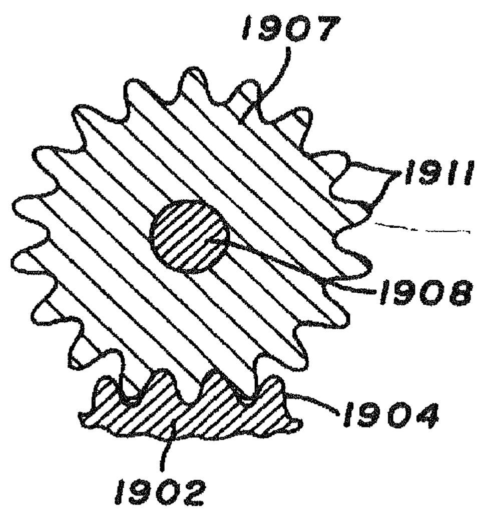

FIG. 24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/14016

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) :A63B 22/02, 24/00
US CL :482/4, 54
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 73/379.01; 198/370.03, 371.01-371.03, 779, 840; 434/247; 482/1-9, 52, 54, 55, 57, 71, 72, 900-903

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 3,451,526 A (FERNANDEZ) 24 June 1969, Figs. 1, 5 and 14-17.	1-20
A	US 3,550,756 A (KORNYLAK) 29 December 1970, Figs. 4-31.	1-20
A	US 5,186,270 A (WEST) 16 February 1993, Figs. 10B and 12.	1-20
A	US 5,238,099 A (SCHROEDER et al) 24 August 1993, Figs. 1-10.	1-20
A	US DES. 340,342 A (NUMMELIN et al) 12 October 1993, see Fig. 1.	1-20

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 DECEMBER 1996	23 DEC 1996
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	Authorized officer Diane L. Smith for JOE H. CHENG
Facsimile No. (703) 305-3590	Telephone No. (703) 308-2667

Form PCT/ISA/210 (second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/14016

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

Please See Extra Sheet.

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☒ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:
1-20

Remark on Protest ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

BOX II. OBSERVATIONS WHERE UNITY OF INVENTION WAS LACKING
This ISA found multiple inventions as follows:

This application contains the following inventions or groups of inventions which are not so linked as to form a single inventive concept under PCT Rule 13.1. In order for all inventions to be searched, the appropriate additional search fees must be paid.

Group I, claims 1-20, drawn to the apparatus for allowing a user to walk or run in any arbitrary direction.

Group II, claims 21-31, drawn to the omnidirectional treadmill for allowing a user to walk or run in any arbitrary direction with the virtual reality means.

Group III, claims 32-42, drawn to the structure of track assembly for allowing a user to walk or run in any arbitrary direction having a plurality side by side endless first belts, sleeve means for accommodating opposite ends of the first belts, means for pivotally connecting adjacent support means to provide an endless second belt, roller means mounted on the frame supporting opposite ends of the second belt, first and second drive means for moving the first and second belt, and control means.

Groups I-III, the inventions in these groups do not relate to a single inventive concept under PCT Rule 13.1 because, under PCT Rule 13.2, they lack the same or corresponding special technical features for the following reasons:

Invention III is prima facie distinct from the apparatus for allowing a user to walk or run in any arbitrary direction, i.e., the omnidirectional treadmill as claimed in Inventions I and II. This invention is directed to the structure of the track assembly having a plurality of side by side endless first belts, sleeve means for accommodating opposite ends of the first belts, means for pivotally connecting adjacent supports means to provide an endless section belt assembly, roller means supporting opposite ends of the second belt assembly, first drive means for moving the second belt assembly in the longitudinal direction, second drive means for moving the second belt assembly in the transverse direction, and control means.

Inventions I and II are distinct in that Invention II requires the virtual reality means to control the omnidirectional treadmill. Because these inventions are distinct for the reasons given above and have acquired a separate status as shown by their different classification and their recognized divergent subject matter, restriction for examination purpose as indicated is proper.